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Upgrading Army Water and Wastewater Treatment Plants

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Water Sludge Management for Military Installations

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Water treatment plants on military installations are required to meet Federal regulations covering sludge disposal. Like civilian plants, these installations had previously discharged the sludge into surface waters or wastewater streams. Compliance with the regulations has now demanded that plants minimize sludge production and consider alternatives to disposal, such as recycling.

This report reviews the state of the art in treatment plant operation and maintenance to help installation Directorates of Engineering and Housing determine optimal practices for their individual plants. This review covers applicable regulations, a characterization of types of sludge produced, disposal options, economics, and possible modifications to existing plant design and O&M procedures.

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WATER SLUDGE MANAGEMENT FOR MILITARY INSTALLATIONS

1 INTRODUCTION

Background

Water treatment plants generate sludge as a result of turbidity removal, softening, and filter-cleaning. The volume of wastes generated, even at small treatment plants, can be high. For example, the softening process can yield sludge constituting 5 percent of the total water volume treated; clarification can produce 1 percent, and backwash water from filter-cleaning can amount to 5 percent of the raw water treated. Although these wastes were once discharged into surface waters or sewers, Federal regulations such as the Clean Water Act now require that sludge be treated and the solids discarded properly or recycled.

Many fixed Army installations have their own water treatment plants and are required to meet the regulations for sludge disposal. To effect proper disposal of the waste products at lowest possible cost, the operation and maintenance (O&M) practices at these installations may require adjustment since most, like civilian plants, had discharged this waste previously.

Water sludges vary significantly among plants, even within the same geographic area, due to differences in treatment techniques and chemical types and dosages. Thus, each plant must make operators aware of proper procedures to ensure efficient operation while complying with regulations. The installation Directorates of Engineering and Housing (DEHs), which are responsible for treatment plant administration, need guidance for determining the optimal O&M profile.

Objective

The objective of this study is to provide up-to-date information for Army DEHs and plant operators as guidance in determining the most suitable sludge disposal methods.

Approach

The literature was surveyed to identify state-of-the-art techniques to ensure optimal treatment and disposal of water treatment plant sludge. Relevant information was organized to present a comprehensive review covering the type of wastes produced, applicable regulations, disposal options, economics, waste characterization, and methods to minimize sludge production, including modifications to the plant and O&M practices.

Mode of Technology Transfer

It is recommended that the information in this report be incorporated into Technical Manual (TM) 5-660, *Operation of Water Supply and Treatment Facilities at Fixed Army Installations*, and TM 5-813-3, *Water Supply, Water Treatment*.

2 SLUDGE PRODUCTION: OVERVIEW

Types of Water Treatment Plants

Water treatment plants can be divided into four general categories according to the types of wastes they produce. First are treatment plants that coagulate, filter, and oxidize a surface water for removal of turbidity, color, bacteria, algae, some organic compounds, and sometimes iron and/or manganese. These plants generally use alum or iron salts for coagulation and produce two waste streams. Most of the waste produced at these plants is sedimentation basin sludge and filter backwash wastes.

The second type of treatment plants are those that practice softening to remove calcium and magnesium by the addition of lime, sodium hydroxide, and/or soda ash. These plants produce clarifier basin sludges and filter backwash wastes. On occasion, plants practice both of these treatment technologies. Softening plant wastes can also contain trace inorganics such as radium that may affect their proper handling.

The third type of plants are those designed to specifically remove trace inorganic substances, such as nitrate, fluoride, radium, and arsenic. These plants use processes such as ion exchange, reverse osmosis, and adsorption. They produce liquid or solid wastes, such as spent adsorption material.

The fourth category of treatment plants includes those that produce air-phase wastes, which are generated during the stripping of volatile compounds. There are very few Army water treatment plants of types 3 and 4. Therefore, this report is limited to treatment of coagulation and softening plant wastes.

Coagulation Waste Streams

Coagulation of surface waters is by far the most commonly used water supply treatment technology. The waste streams from these plants comprise the majority produced by the water industry. They are also some of the more difficult wastes to treat. Figure 1 shows a conventional coagulation treatment process with the typical wastes produced. Some water plants have a presedimentation step. This step is generally used only when the raw water source is high in settleable solids. Although an oxidant or small amount of polymer may be added, often no chemical is added prior to presedimentation. It is generally accepted that as long as coagulant is not added, and therefore the solids are essentially only those settled from the raw water, then these solids can be discharged back to the watercourse on a controlled basis. Since this type of handling allows some level of discharge, presettling solids are not specifically addressed in this report.

The coagulation process itself generates most of the waste solids. Generally, a metal salt (aluminum or iron) is added as primary coagulant. Powdered activated carbon, polymer, clay, lime, or activated silica are other solids-producing chemicals that can also be used. All waste solids, along with solids in the raw water, are usually removed in a sedimentation tank or clarifier. In areas with very good raw water quality, sedimentation basins are occasionally omitted and the solids removed by filtration only. This process, commonly known as "direct filtration," is usually used for waters with low turbidity and requires low levels of coagulant. All solids removed in this process are collected with filter backwash water.

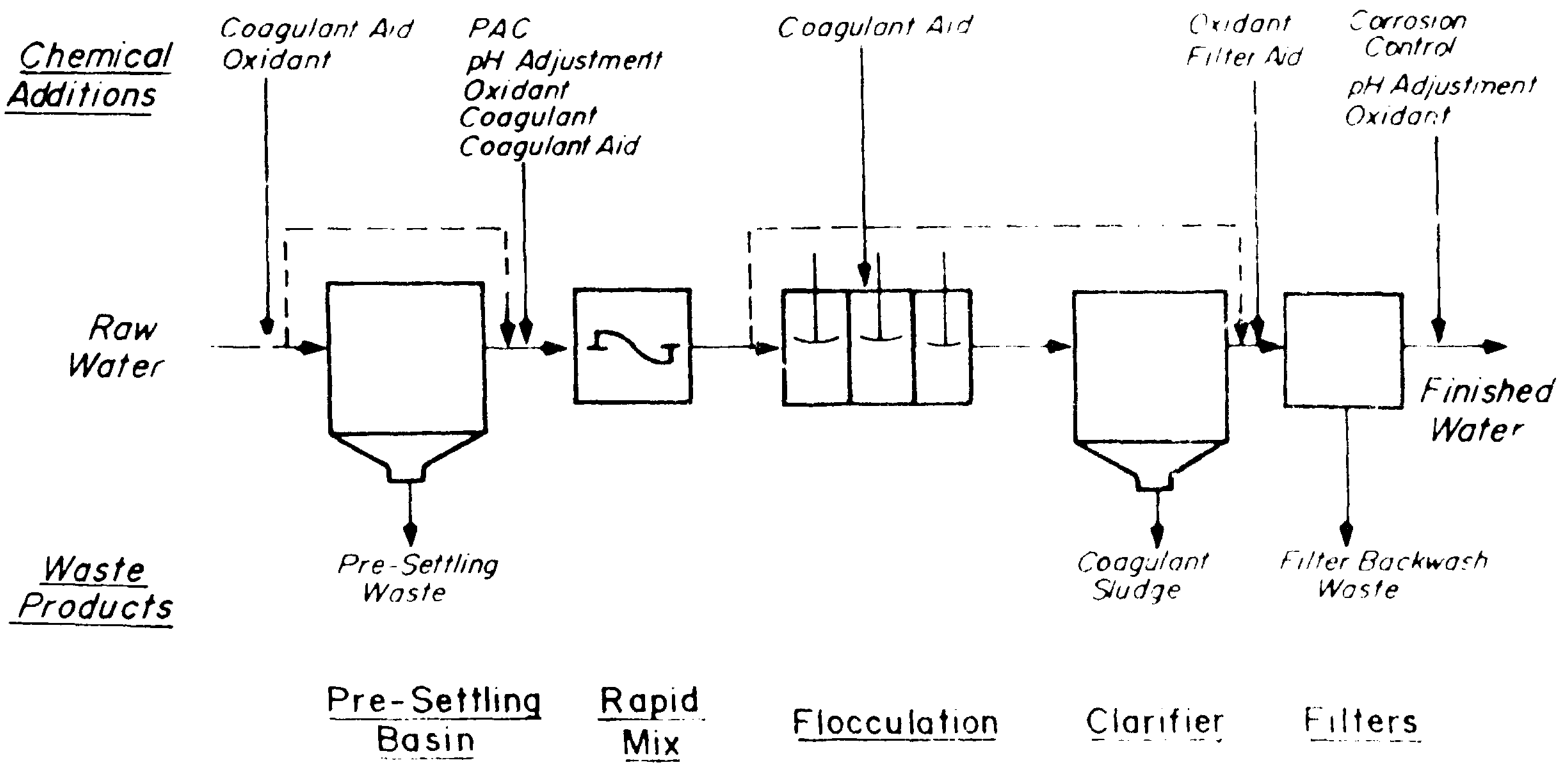

Figure 1. Waste-producing processes in coagulation plants. (Source: D. A. Cornwell et al., *Water Treatment Plant Waste Management* [AWWA Research Foundation, June 1987]. Used with permission.)

The amount of solids produced depends on the raw water quality and chemical addition. (Chapter 4 discusses how to determine the amount of solids produced.) The volume of sedimentation basin sludge produced depends on both the solids' properties and the method by which they are removed from the basin. Manual cleaning of sedimentation basins results in batch production of sludge and makes subsequent sludge handling more difficult. It may be desirable to retrofit the basins with continuous sludge removal equipment. which may be difficult to accomplish due to basin configurations. However, producing a fairly continuous, consistent flow of sludge to the sludge treatment system is often a critical factor in successful dewatering.

The second major waste stream produced is from the batch process of backwashing the filters. Solids collected on the filters are those remaining after sedimentation, caused by the addition of a filter aid, or formed by oxidation of perhaps iron or manganese. In a direct filtration process, these are the only solids produced. The volume is a function of the amount of water used for backwashing. This waste stream is produced at very high flow rates for short periods of time and proper equalization is required.

Another waste product occasionally found in a coagulation-based plant is spent granular activated carbon (GAC). GAC is sometimes used in the filters or during postfiltration. When its use is for taste and odor removal, the carbon is disposed of after its capacity is exhausted. When it is used for continuous low-level organics removal, the carbon is usually regenerated onsite, with essentially no waste stream produced.[1]

Softening Waste Streams

Wastes produced from softening plants represent the second major waste product generated by the water industry. They usually are more easily dewatered than are coagulant wastes. There are many variations of the softening process. Chemical addition, flow processes, and the subsequent waste amounts and characteristics all depend on the raw water hardness and alkalinity constituents, as well as the desired finished water quality. Since softening is generally a process used to improve the chemical characteristics and esthetics of the finished water rather than its potability, subjective decisions can be made as to the final desired quality. Factors that should enter into that decision process include the effects on sludge handling and costs.

Softening is usually done by chemical precipitation of the calcium and magnesium. This process is called "lime/soda ash softening," and is by far the most widely used softening method. Lime is added for the removal of carbonate hardness and is supplemented with soda ash for noncarbonate hardness removal if required. From the standpoint of sludge economics, it is desirable to leave as much magnesium hardness in the water as considered acceptable. Often the final magnesium hardness can be allowed to remain around 40 ppm* as $CaCO_3$ or slightly higher and not have an adverse effect on residential water heaters. The less magnesium in the sludge, the easier it is to dewater.[2]

Figure 2 is a rather simplified softening plant schematic. Several variations of Figure 2 are used to obtain the desired water quality and minimize costs. In softening plants, there are usually two waste streams produced: the settled solids from the

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[1] D. A. Cornwell et al., *Water Treatment Plant Waste Management* (American Water Works Association [AWWA] Research Foundation, June 1987).

*Metric conversion factors appear on p 88.

[2] D. A. Cornwell et al.

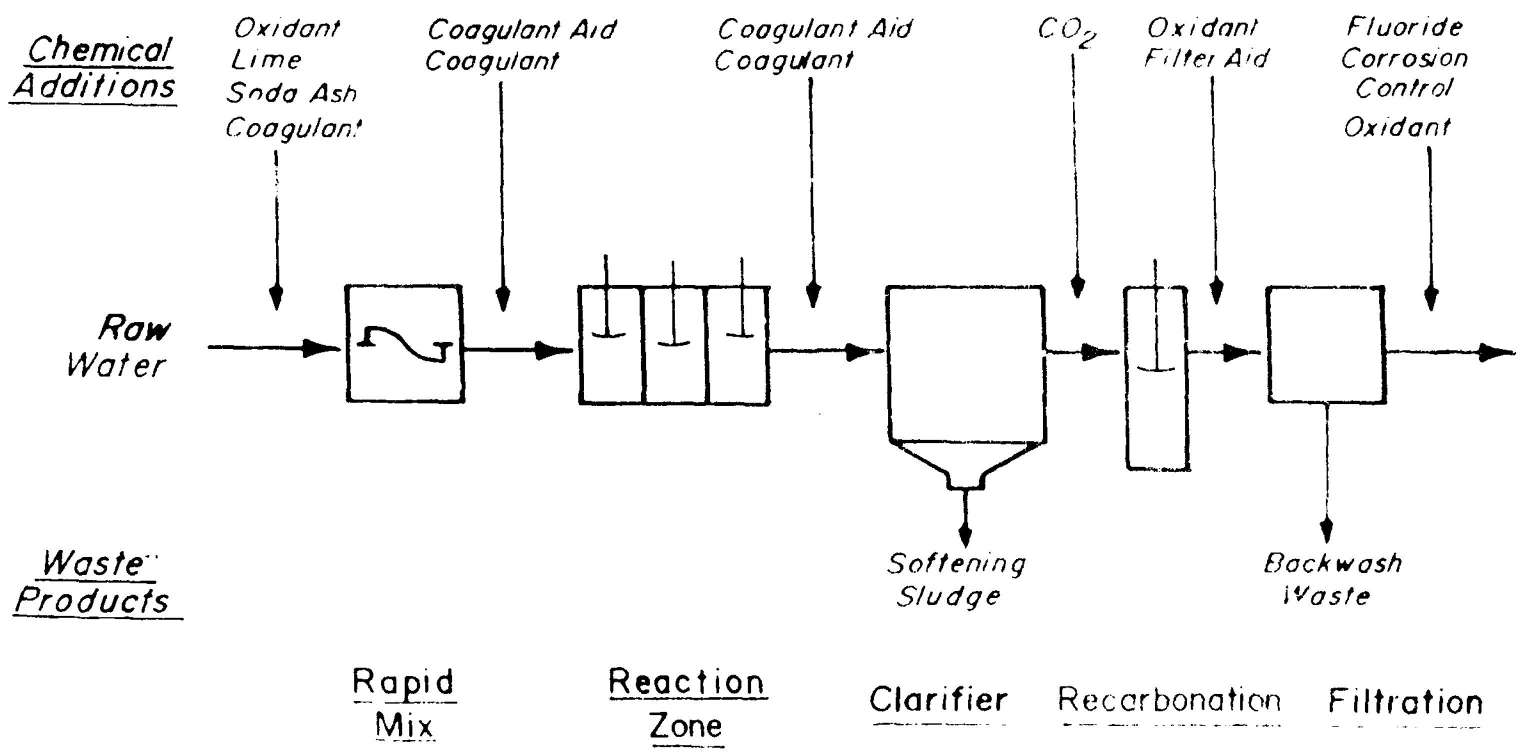

Figure 2. Waste-producing processes in softening plants. (Source: D. A. Cornwell et al., *Water Treatment Plant Waste Management* [AWWA Research Foundation, June 1987]. Used with permission.)

clarifier and the backwash wastes. Some plants add a polymer or metal salt to help remove fine precipitates, color, or turbidity present in the original water. Again, from a sludge management viewpoint, the addition of metal salts should be held to a minimum as the presence of metal hydroxides could greatly increase sludge treatment costs. The use of polymers and slurry recirculation can help minimize the need for these coagulants.

The reaction zone and clarifier are combined into a single solids contact unit in many plants. In these plants, sludge can be fairly uniformly withdrawn from the sludge blanket and a consistent suspended solids concentration and flow rate maintained. Plants that have separate clarifiers are often equipped with scrapers for sludge removal. Although not quite as easy to control as the sludge blanket units, the separate clarifiers can produce a fairly consistent sludge. As with coagulation plants, filter backwash water is produced at high flow rates for short periods of time. The filter backwash water may require equalization basins prior to treatment or discharge.

3 WASTE DISPOSAL: REGULATIONS AND METHODS

Waste Stream Disposal Regulations

The applicable regulations governing water plant waste disposal can be divided into two categories. Those limiting the direct discharge of wastes into a water course are associated with the Clean Water Act (CWA).[3] The second set of regulations affects land disposal of water plant wastes. These regulations include the Resource Conservation and Recovery Act (RCRA)[4] and the Comprehensive Environmental Response, Compensation and Liability Act (CERCLA).[5] Interpretation of the regulations as they affect water plant wastes varies considerably from state to state. Specific regulations should be obtained from local and state authorities.

Table 1 summarizes the environmental statutes affecting water plant waste disposal. To discharge to a body of water, a permit must be obtained under the National Pollutant Discharge Elimination System (NPDES) as authorized under the CWA. In-stream water quality criteria and standards have been set to protect aquatic and human life. Standards are generally established by individual states and are enforceable at that level. Criteria are defined as guidelines or goals established by the U.S. Environmental Protection Agency (USEPA). Allowable pollutant concentrations in a discharge can be set to meet in-stream water quality standards, the criteria levels, or other levels as the individual states may deem appropriate for a specific watercourse.

USEPA has developed about 50 guidance documents covering direct discharge of industrial wastes. However, it has not published guidance on water plant wastes. Therefore, discharge decisions are made either by regional USEPA offices or by the individual states delegated to write their own permits. It is up to the permit writer to rule on the best available treatment technology for each plant on a case-by-case basis.

Discharge to wastewater treatment plants usually is governed by the individual plant's pretreatment regulations. State agencies also may provide some specific guidelines.

Land Disposal Regulations

Land disposal regulations can apply to landfilling of solid wastes or land application of solid- or liquid-phase wastes. If the waste is not hazardous and does not contain low-level radioactivity, it can be discarded in an industrial waste landfill. Some states allow disposal of water plant wastes in a general sanitary landfill rather than an industrial waste landfill. However, very often in these states, requirements for the construction of a general sanitary landfill are as stringent as these for an industrial waste landfill.[6] These landfills are governed by individual state requirements. As a minimum, these regulations require that the waste not contain any free water (i.e., water that will drain by gravity). For exrmple, Virginia allows the disposal of water plant sludges in landfills

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[3] Public Law (PL) 95-217, *Clean Water Act of 1977*, 91 Stat. 1566.
[4] PL 94-580, *Resource Conservation and Recovery Act of 1976*, 90 Stat. 2795.
[5] PL 96-510, *Comprehensive Environmental Response, Compensation, and Liability Act of 1980*, 94 Stat. 2767.
[6] D. A. Cornwell et al.

Table 1

Regulatory Acts Governing Water Plant Waste Disposal

Disposal Option	Applicable Regulations*
Stream	NPDES (CWA) In-Stream Water Quality Criteria (CWA) Discharge Guidance Documents
Wastewater plant	Pretreatment Standards (CWA)
Landfill	RCRA CERCLA State SW Requirements (RCRA) Low-Level Radioactive Waste Requirements (state, NRC, DOT, USEPA)
Land application	Sludge Disposal Regulations (CWA) Low Level Radioactive Waste Requirements (state, NRC, DOT, EPA)

*CWA = Clean Water Act; RCRA = Resource Conservation and Recovery Act; CERCLA = Comprehensive Environmental Response, Compensation and Liability Act.

if the solids concentration is higher than 20 percent. If the solids concentration is 20 percent to 35 percent, the sludge is to be mixed 6:1 (by volume) with solid waste; if this concentration is 35 percent to 60 percent, they are to be mixed 4:1; and if the solids concentration is more than 60 percent, the sludge can be discarded without mixing (in dry weather).[7]

If the waste is classified as hazardous, its disposal is governed by RCRA. Water plant wastes containing radium may come under the jurisdiction of the Nuclear Regulatory Commission, USEPA, and the Department of Transportation. Currently, the ultimate authority for regulation of water plant wastes containing radium lies with the individual states.

Ultimate Solids Disposal

Water treatment plant sludges historically have been discharged either directly or indirectly into a surface water. In 1953, 92 percent of 1600 plants surveyed disposed of

[7] D. A. Cornwell et al.

their sludges in streams or lakes.[8] This method, although still widely used, is being discontinued under the pressure of state regulatory agencies and the Federal laws discussed above. Results from a 1979 survey[9] of 75 alum coagulation plants and a 1981 survey[10] of 100 softening plants are shown in Table 2. By the time of these surveys, the percentage of softening plants discharging sludge to rivers or lakes had decreased to 13 percent, while 20 percent of alum coagulation plants still practiced this method of sludge disposal.

Disposal Options

Eight basic sludge disposal options can be used by water treatment plants:[11]

1. Discharge to waterway.

2. Discharge to sanitary sewers.

3. Codisposal with sewage sludge at a wastewater treatment plant.

4. Lagooning with and without natural freezing, requiring ultimate disposal of the residue.

5. Mechanical dewatering with landfilling of residue.

6. Coagulant recovery.

7. Land application, especially of softening sludge.

8. Use as building or fill materials.

Discharge to Waterway

Discharge of solids to surface streams is prohibited in most states.[12] The American Water Works Association (AWWA) survey of softening plants in 1981 found that of the plants still using direct discharge to a river (13 percent), half of those intended to implement a sludge treatment method in the near future.[13]

Discharge to Sanitary Sewers

The practice of discharging water treatment plant solids to sanitary sewers transfers the solids handling problem from the water treatment plant to the waste treatment

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[8]AWWA Committee Report, "Disposal of Water Treatment Waste," *Journal of the American Water Works Association (JAWWA)* (December 1972).

[9]D. A. Cornwell and J. A. Susan, "Characteristics of Acid Treated Alum Sludges," *JAWWA*, Vol 71, No. 10 (October 1979).

[10]AWWA Sludge Treatment and Disposal Committee Report, "Lime Softening Sludge Treatment and Disposal," *JAWWA*, Vol 73, No. 11 (November 1981).

[11]R. B. Williams and G. L. Culp (Eds.), *Handbook of Public Water Supply* (Van Nostrand Reinhold, 1986).

[12]L. E. Lang et al., *Evaluating and Improving Water Treatment Plant Processes at Fixed Army Installations*, Technical Report N-85/10/ADA157306 (U.S. Army Construction Engineering Research Laboratory, May 1985).

[13]AWWA Sludge Treatment and Disposal Committee Report.

plant. The overall cost for treating water and wastewater solids can be lowered by consolidating the solids handling equipment and personnel in one facility. Several factors must be evaluated if this approach receives serious consideration for a given application. These include:

1. The ability of the collection system (pipelines and pumping facilities) to handle the flow and solids loadings, which may require equalization facilities to eliminate shock loadings.

2. The effect on treatment facilities and operations.

3. Capital and operating costs.

A major consideration is the ability of the sewer collection system and wastewater treatment plant to accept the increased hydraulic and solids load caused by the addition of water treatment plant wastes. The direct discharge to the sewer can cause a hydraulic overload of the collection system, or a hydraulic surge large enough to cause the clarifier's performance to deteriorate. Flow equalization tanks may be needed at the water plant if the volume of water plant waste is large in proportion to the sewage flows.[14] Release during low-sewage-flow periods may be desirable. However, there must be sufficient flow in the sewer to provide adequate velocities to prevent deposition of the sludge in the sewer. Generally, a velocity of about 2.5 ft/sec should be maintained to prevent sedimentation of hydroxide sludge solids. Lime sludge may have settling velocities much higher than coagulant sludges, and it can be difficult to prevent its deposition in sewer lines.[15]

Table 2

Methods for Disposal of Water Treatment Plant Waste*

Method	Percent of Plants Using Method	
	Softening Sludge	Coagulation Sludge
Sludge lagoon	34**	43
Sanitary sewer	8	27
River or lake	13	20
Recalcination	5	--
Direct land application	5	--
Other	--	10

*Adapted from R. B. Williams and G. L. Culp (Eds.) *Handbook of Public Water Supply* (Van Nostrand Reinhold, 1986).

**Fifty-six percent of plants surveyed had sludge lagoons, 60 percent of which were considered "permanent lagoons"; thus, 34 percent of plants used sludge lagoons for disposal.

[14] R. B. Williams and G. L. Culp.

[15] D. A. Cornwell et al.

Most of the solids from the water plant sludges will be removed in the primary clarifier. The solids handling system at the wastewater treatment plant must be able to accommodate the additional solids load. For example, disposal of large amounts of gelatinous hydroxide floc in an anaerobic digestion sand-drying bed system may make it difficult to obtain proper solids dewatering.[16] The dewatering characteristics of the combined sludges should be studied before this approach is adopted.

Culp and Wilson studied the effect of adding alum sludge to an activated sludge wastewater treatment facility and reported no significant benefit or detriment to the treatment process or the anaerobic digester.[17] In addition, AWWA concluded that if the water sludge is equalized and the dose kept below 150 to 200 ppm, no direct effect on the activated sludge process is likely to occur.[18] No change in overall biological oxygen demand/chemical oxygen demand (BOD/COD) or suspended solids (SS) removal would be expected, but these parameters should be monitored. If primary clarifiers are not present, however, some adverse impacts may result. In that case, the activated sludge process will need to operate with a higher mixed liquor SS concentration to maintain the desired mixed liquor volatile SS concentration, and the secondary clarifiers may become overloaded, resulting in solids carryover.[19]

The direct discharge of alum sludge to a sanitary sewer system has been practiced with success in four large U.S. cities: Detroit, MI, Wilmington, DE, Washington, DC, and Philadelphia, PA. Although solids loadings at the wastewater treatment plants are increased because of the alum sludge, no operating difficulties have been reported).[20]

Codisposal

Codisposal of softening sludges with other wastes is another option. Lime sludge could be used for many reasons, including:[21]

1. Elevation of pH.

2. Provision of a bulking agent.

3. Neutralization of acid wastes to bring them within NPDES permit levels.

4. Assistance in pretreatment of industrial wastes.

5. Incineration to produce high-alkaline ash.

The lime sludge could be combined with other wastes generated at the installation or at nonmilitary activities in the region. The most favorable codisposal option would

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[16] R. B. Williams and G. L. Culp.
[17] R. L. Culp and W. I. Wilson, "Is Alum Sludge Advantageous in Wastewater Treatment?" *Water and Wastes Engineering* (July 1979).
[18] D. A. Cornwell et al.
[19] D. A. Cornwell et al.
[20] D. A. Cornwell, "Management of Water Treatment Plant Sludges," *Sludge and Its Ultimate Disposal* (Ann Arbor Science, 1981).
[21] AWWA Committee on Sludge Treatment and Disposal Report.

depend on the opportunities available and the feasibility of handling the wastes to make the treatment effective.

Lagoons

Mechanical dewatering is expensive, especially for small plants of less than 50 million gal/day (mgd).[22] The best alternative for small Army plants may be lagooning, which is also an option for larger plants where large tracts of inexpensive land are available or can be obtained. A detailed description of lagoon dewatering appears in Chapter 5. In many instances, storage of dilute or concentrated water treatment plant solids in lagoons is considered to be final disposal. In truth, this storage is a postponement of the ultimate disposal requirement.

Mechanical Dewatering/Landfill

Again, detailed descriptions of various mechanical dewatering processes are given in Chapter 5. Sanitary landfills are used to dispose of solids after mechanical dewatering as well as those from lagoons or sand-drying beds. Disposal in landfills requires concentration of the solids to a semisolid or cake form. The problems that occur in landfills are related to the semisolid form of sludge. Caution should be taken in landfilling coagulant sludges because of the possible leaching of aluminum and other metals from them. Municipal solid waste landfills are anaerobic, may produce volatile acids, and hence have a pH in the vicinity of 5 to 5.5. This pH will allow for some dissolution of aluminum and other metals from the sludge. Landfills equipped with liners and leachate collection systems are desirable.

Creating a dedicated landfill--one that receives only the water plant sludge--is also a widely practiced alternative. In this case, however, the utility must design and operate the landfill.[23]

Coagulant Recovery

Even with aluminum or iron coagulant recovery, there is some remaining solids residue for disposal. Dry solids remaining may be 50 to 65 percent of the original solids. The solids left after lime recalcination may be up to 20 times less than the original quantity of lime sludge.[24]

Land Application

Land application is practiced to a limited extent for alum sludge disposal and more widely for lime sludge disposal. This disposal method is a potential use for a resource otherwise discarded at great expense, and it can be an economical, beneficial solution to waste disposal problems.

In many farming regions, the application of nitrogen fertilizers reduces soil pH. Farmers normally apply enough lime to obtain the pH conditions for optimal crop yield. Lime sludges from water plants are as effective as quarry limestone in neutralizing soils. In fact, the Ohio Department of Health reported that the total neutralizing power (TNP) of lime sludge is 92 to 100 compared with 60 to 90 for commercially available

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[22] R. B. Williams and G. L. Culp.
[23] D. A. Cornwell et al.
[24] R. B. Williams and G. L. Culp.

materials.[25] Because softening sludges contain a large amount of calcium carbonates and offer a high degree of neutralization, this resource should be used when practical for soil conditioning. The addition of softening sludge also increases the porosity of tight soils, making them more workable for farming.[26] Therefore, it is suggested that giving sludge to neighboring farmers may merit investigation.

The solids content of softening sludge discharged from clarifiers is 1 to 5 percent. For land application, the sludge can be thickened to a liquid at 8 to 10 percent solids or as a solid after dewatering at about 40 percent solids. Handling problems will be encountered if conventional farming equipment is used and the solids content of the sludge is between these values.[27] The sludge can be applied to farmlands by either spraying liquid sludge from a tank truck or by spreading and tilling dewatered lime sludge from a hopper-bed truck with a spinner device for spreading it.

Transportation costs and farmer acceptance appear to be the major drawbacks to more widespread land application of lime sludge.[28] Also, the lime is only needed seasonally by the farmer but is produced continually at the water plant.

Alum sludges have essentially no nutrient value and therefore little use as a soil conditioner.[29] In a study by Bugbee and Frink, land application of alum sludge inhibited the growth of lettuce, which the researchers attributed to phosphorus deficiencies.[30] Alum sludge improved the physical characteristics of the media, aeration, and moisture-holding capacity but adsorbed phosphorus, therefore making it unavailable for plants. The same study found little effect on deciduous and coniferous forested lands. Little change in tree growth, nutrient levels, and the appearance of the forest floor was noticeable after 124,000 gal/acre of liquid alum sludge containing 1.5 percent solids was applied. Plant nutrient uptake showed there was no effect due to liquid alum sludge application.

Grabarek and Krug conducted a follow-up study with application of alum sludge containing 1.5 percent solids on forest plots in Connecticut.[31] They concluded that alum sludge has no significant impact with respect to organic or metal leachate production, or to aluminum toxicity in trees (mainly sugar maples). The sludge substantially dewatered within 2 weeks and was barely noticeable in 2 months. The only adverse impact found was the binding of soil phosphorus.

[25] Ohio Department of Health, *Supplement to Report on Waste Sludge and Filter Washwater Disposal From Water Softening Plants* (September 1969).

[26] G. A. Russell, "Agricultural Application of Lime Softening Residue," paper presented at the Illinois AWWA Section Meeting (March 1980).

[27] R. B. Williams and G. L. Culp.

[28] D. A. Cornwell et al.

[29] D. A. Cornwell et al.

[30] G. J. Bugbee and C. R. Frink, "Alum Sludge as a Soil Amendment: Effects on Soil Properties and Plant Growth," Bulletin 827 (Connecticut Agricultural Experiment Station, November 1985).

[31] R. J. Grabarek and E. C. Krug, "Silvicultural Application of Alum Sludge," *JAWWA* (accepted for publication).

Lin and Green found the application of alum sludge to corn and soybean farmland had neither beneficial nor adverse effects on soils and crops.[32] The plant population and corn yield at the highest sludge application rate (20 ton/acre) showed no difference from that of the control plots. Nutrients and heavy metals analyses (for 11 to 16 parameters) of grains, whole plants, and leaves of both crops showed insignificant effects from the addition of alum sludge.

Use for Building or Fill Material

Alum sludge has been suggested for use as a plasticizer in the ceramics industry as part of refractory bricks, and as a road-stabilizing agent.[33] In Atlanta, GA, for example, dewatered alum sludge is transported to a residential building site where it is used as fill.[34] Sludge cake is spread and compacted by a bulldozer to fill areas as deep as 6 ft. No problems have been reported with driving loaded trucks over the compacted sludge cake.

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[32]S. D. Lin and C. D. Green, *Wastes From Water Treatment Plants: Literature Review, Results of an Illinois Survey and Effects of Alum Sludge Application to Cropland* (Illinois State Water Survey, November 1987).

[33]AWWA Committee Report (December 1972).

[34]AWWA Committee on Sludge Disposal, "Water Treatment Plant Sludges--An Update of the State of the Art, Parts I and II," *JAWWA* (September and October 1978).

4 CHARACTERISTICS OF WATER TREATMENT PLANT WASTES

Four important areas need to be addressed when characterizing water plant wastes:[35]

1. Type of waste generated.

2. Quantity of waste generated.

3. Classification by physical properties and dewatering characteristics.

4. Specific constituents in the waste streams, particularly as they may affect proper disposal.

There is no such thing as a "typical" water plant waste. Waste characteristics must be analyzed at each installation. However, certain types of water plant wastes have common characteristics, and there are standard test methods that can be used to evaluate them.

Types of Wastes Generated

Approximately 70 percent of the water plant waste is generated from the coagulation process. In this process, hydrolyzing metal salts or synthetic organic polymers are added to coagulate suspended and dissolved contaminants and produce relatively clean water suitable for filtration. Most of these coagulants and the impurities they remove settle to the bottom of the settling basin where they become part of the sludge. These sludges are classified as alum, iron, or polymeric, depending on which primary coagulant is used. Sludges produced in treatment plants that use lime or lime and soda ash for water softening constitute another 25 percent of the water industry's waste production. Therefore, most of the waste generated involves water treatment plants using coagulation or softening processes. Other solid/liquid wastes produced in the water industry include those from polymer coagulation, iron or manganese removal plants, spent precoat filter media, and slow sand filtration plants.

Amount of Waste Generated

Table 3 shows ranges of volumes and solids content for sludges produced from turbidity removal, softening, and filter backwash. Determining the amount of sludge produced can be a difficult task. The quantity of solid/liquid wastes (i.e., sludge) generated from water treatment plants depends on the quality of the water source, dosage of chemicals used, performance of the treatment process, and method of sludge removal. In addition, sludge volumes can vary by orders of magnitude for different months of the year.

Determining the amount of waste produced requires a long-term data compilation and it is wise for utilities to begin collecting these data, even if there are no immediate plans to begin a new waste management program.

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[35]AWWA Committee Report (December 1972).

Table 3

Water Treatmemt Plant Waste Volumes and Characteristics

Waste Type	Reported Value	Ref.*
Coagulation (Turbidity Removal) Sludge		
Sludge volume as % of raw water treated	<1.0	a
	0.1 - 3.0	h
	0.1 - 3.5	a
Low/moderate turbidity (%)	0.1 - 1.0	h
Suspended solids concentration (mg/L)	100 - 1000	b
Solids content after long-term settling (%)	10	c
	4 - 36	d
Softening Sludge		
200 ppm dry sludge produced per 100 ppm hardness removed		e
2.5 lb sludge/1 lb lime used		f
Solids content of settled sludge (%)	2 - 30	a
Ca:Mg ratio > 0.5	Easily dewatered	g
Ca:Mg ratio < 2	Difficult to dewater	g
Sludge volume as % of raw water treated	0.5 - 5	h
Filter Backwash Wastewater		
Wastewater volume as % of filtered water volume	1 - 5	g

*References: (a) AWWA Committee on Sludge Disposal, "Water Treatment Plant Sludges--An Update of the State of the Art, Parts I and II," *JAWWA* (September and October 1978); (b) J.W. Clark, *Water Supply and Pollution Control* (Dun & Donnelly, New York, 1977); (c) *The Quest for Pure Water* (AWWA, 1981); (d) R.J. Calkins and J.T. Novak, "Characterization of Chemical Sludges," *JAWWA*, Vol 65, No.5 (June 1973); (e) *Water Treatment Plant Design* (AWWA, 1971); (f) L.R. Howson, "Sludge Disposal," *Water Treatment Plant Design* (Ann Arbor Science, 1979); (g) AWWA Sludge Treatment and Disposal Committee Report, "Lime Softening Sludge Treatment and Disposal," *JAWWA*, Vol 73, No. 11 (November 1981); (h) D.A. Cornwell et al., *Water Treatment Plant Waste Management* (AWWA Research Foundation, June 1987).

There are three methods to determine how much sludge is generated: calculations, coagulant mass balance analysis, and field determination. It is advisable to use and cross check all three methods since none is completely accurate.

The amount of sludge produced in an alum coagulation plant for the removal of turbidity can be calculated fairly closely by Equation 1:

$$S = 8.34Q\ (0.44Al + SS + A) \qquad \text{[Eq 1]}$$

where:

- S = sludge produced (lb/day)
- Q = plant flow (mgd)
- Al = alum dose as 17.1 percent Al_2O_3 (ppm)
- SS = raw water suspended solids (ppm)
- A = additional chemicals added such as polymer, clay or activated carbon (ppm)

One difficulty in using this equation is that most plants do not routinely analyze raw water SS concentrations. If a utility does not continually measure SS, it cannot develop the correlation between turbidity (Tu) and SS. The relationship is:

$$SS\ (mg/L) = b \times Tu \qquad \text{[Eq 2]}$$

where the values of b for low-color, mainly turbidity removal plants can vary from 0.7 to 22. By measuring SS and turbidity weekly, a correlation can be developed for the particular raw water source used. After that, a monthly correlation may be good enough.

A second method used to estimate total sludge weight produced for coagulant sludges is to analyze the conservation of coagulant mass balance. Whatever is added in the coagulation process reappears in the sedimentation basin solids, backwash solids, or finished water. First, the aluminum or iron content of the coagulant must be analyzed. It can be assumed that dry weight alum is 9.1 percent aluminum. Then, several sludge, backwash solids, and finished water samples are collected and analyzed for aluminum (or iron). The pH of the solids is lowered to 1 for 10 to 15 min; the solids are then filtered and the filtrates analyzed for aluminum (or iron). This method solubilizes the aluminum hydroxide but not the aluminum in the clay that might be present. A second sample of unacidified sludge is analyzed for SS concentration. The total amount of sludge can then be computed. An example of this method is given in Cornwell et al.[36]

The third way to determine sludge quantities is through field methods. Often, a water treatment plant has manually cleaned sedimentation basins or does not have a way to continually measure sludge flow and dry weight. To estimate sludge production, the sludge should be allowed to collect in the basins for a specific amount of time after all basins have been cleaned. A cross section of sludge depth can be taken from each basin by using a clear acrylic tube with a foot valve called a "Sludge Judge." The Sludge Judge can also be used to collect a composite depth of sludge from several locations in the basins to analyze SS. A very rough projection of sludge production can be made, but this estimate should be supplemented by use of the other two procedures.

[36]D. A. Cornwell et al.

A general equation for estimating sludge production at plants that use a softening process with or without addition of alum, iron, or polymer is:

$$S = 8.143(Q)(2.0\ Ca + 2.6\ Mg + 0.44\ Al + 1.9\ Fe + SS + A) \qquad [Eq\ 3]$$

S = sludge produced, lb/day
Q = plant flow, mgd
Al = alum dose as 17.1 percent Al_2O_3 (ppm)
Fe = iron dose as Fe (ppm)
SS = raw water suspended solids (ppm)
A = additional chemicals such as polymer, clay, or activated carbon (ppm)
8.143 = constant for use with Engish units (84.4 is the constant for use with the metric units shown)

It should be noted that the above procedures will allow estimation of the dry weight of sludge produced, not the volume.

The important characteristics of water treatment plant sludges are those that affect handling and disposal. The general goal is to reduce the bulk of the sludge and produce a material suitable for disposal or recovery processes. According to Knocke and Wakeland,[37] the physical properties of sludge affecting their handling and disposal are "macroproperties" such as specific resistance, settling rates, and cake solids concentrations, and "microproperties" such as particle size distribution and density. They have evaluated several of the microproperties and their effect on dewatering of alum and lime sludges.

General Characteristics

Alum Sludges

In the absence of significant organic pollution in the raw water, coagulant sludges are essentially biologically inert and have a nearly neutral pH.[38] The sludge is generally thixotrophic (i.e., the plasticity of the sludge changes with agitation) and gelatinous. Sludges from plants obtaining raw water from river supplies with a fairly high silt content are not as gelatinous as that from plants receiving raw water from lakes or reservoirs. Coagulant sludges such as alum sludge can be characterized at varying solids contents, as shown in Table 4.[39]

Softening Sludges

Softening sludges are generally white, have no odor, and have low BOD and COD. Lime sludges can be characterized at varying solids content as shown in Table 5.

[37] W. R. Knocke and K. L. Wakeland, "Fundamental Characteristics of Water Treatment Plant Sludges," *JAWWA*, Vol 75, No. 2 (May 1975).
[38] R. B. Williams and G. L. Culp.
[39] R. B. Williams and G. L. Culp.

Table 4

Alum Sludge Characteristics*

Solids Content (%)	Sludge Character
0 - 5	Liquid
8 - 12	Spongy, semisolid
18 - 25	Soft clay
40 - 50	Stiff clay

*Source: R. B. Williams and G. L. Culp (Eds.), *Handbook of Public Water Supply* (Van Nostrand Reinhold, 1986). Used with permission.

Table 5

Lime Sludge Characteristics*

Solids Content (%)	Sludge Character
0 - 10	Liquid
25 - 35	Viscous liquid
40 - 50	Semisolid, toothpaste consistency
60 - 70	Crumbly cake

*Source: R. B. Williams and G. L. Culp (Eds.), *Handbook of Public Water Supply* (Van Nostrand Reinhold, 1986). Used with permission.

Tests To Determine Physical Properties

Tests to define macroproperties of sludges can be used to assist in the selection of dewatering aids and to determine relative ease of dewatering. They also can be useful as an operating tool to determine conditioning doses on a routine basis. The four main tests are specific resistance, time-to-filter test, filter leaf, and capillary suction time.

Specific Resistance Test

The specific resistance test is used to optimize sludge dewatering performance. It is most valuable for evaluating chemical conditioning of sludge for full-scale operations. The test uses a simple Buchner funnel as shown in Figure 3. A 0.38-gal portion of sludge is added to the funnel and the volume of filtrate generated at various times reported. Based on the Carmen-Kozeny equation for flow through porous media, an equation has been developed to describe flow through the sludge cake and associated support media. Ultimately:

$$R = \frac{2bPA^2}{mwR_r} \qquad \text{[Eq 4]}$$

where:

R = specific resistance (sec^2/g) of sludge

b = slope of line (sec/cm^6) from plot of time/volume vs. volume

P = vacuum applied (cm of water)

A = filter area (cm^2)

m = filtrate viscosity (poise)

w = dry weight of solids per volume of filtrate (g/cm^3)

Rr = specific resistance (sec^2/g) of filter media

Specific resistance data are not recommended for sizing full-scale equipment, but are useful for conditioning studies.

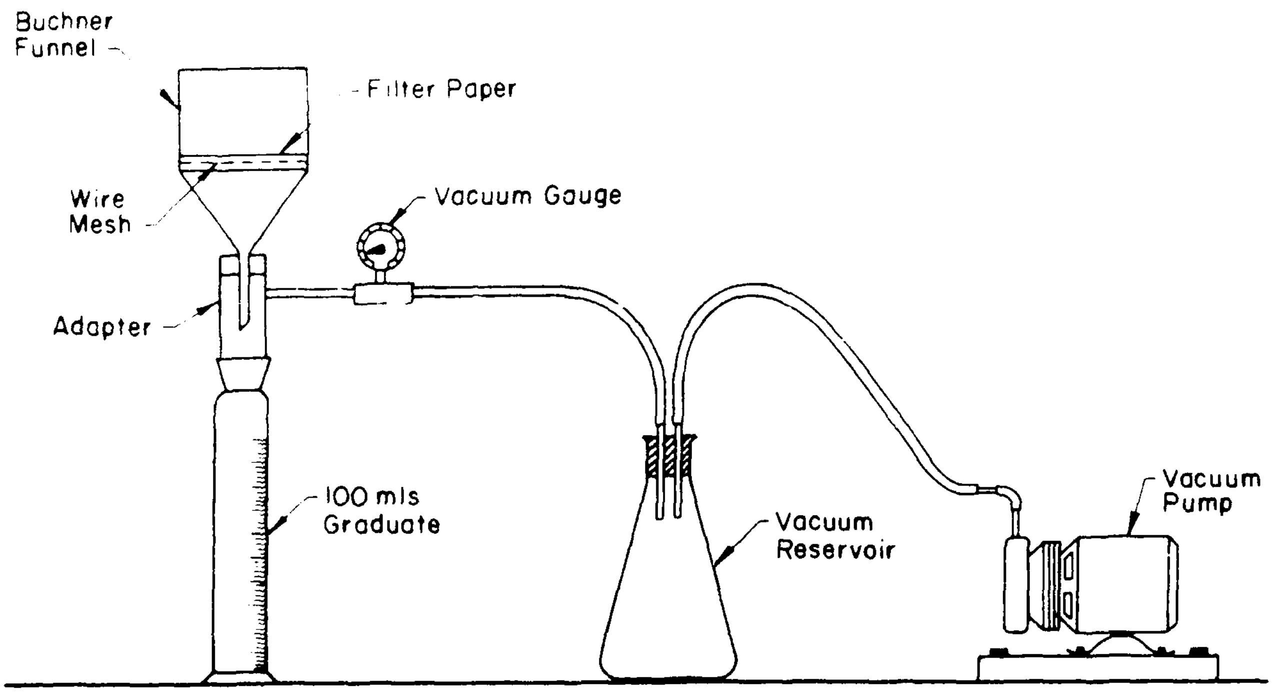

Figure 3. Buchner funnel apparatus.

Time-to-Filter Test

A simplification of the specific resistance test is the time-to-filter test (TTF). The same Buchner funnel apparatus is used. However, in this test, the data collected are the time for one-half the volume to filter.

Filter Leaf Test

The filter leaf test duplicates on a laboratory scale the vacuum filter operations as closely as possible. With this test, solids concentration of sludge, vacuum level, filter media, cycle time, sludge conditioning, and submergence time (or percentage filter submergence) can be varied. The filter cloth of interest should be used. Sludge samples can be prepared in a standard jar test apparatus and transferred to a beaker. The filter to be tested is submerged in a well mixed sludge as shown in Figure 4. The vacuum level and cake-forming cycle should be the same as in full-scale equipment. At the end of the form time, the filter is removed and dried in the atmosphere at the same vacuum level and drying time used in normal operations. At the end of the drying cycle, the filter cake thickness is measured and the solids are removed from the filter media. The filtrate volume, wet and dry weight of solids recovered, and solids content of the cake are normally determined. The quality of filtrate may also be of interest. The filter yield is then calculated as follows:[40]

$$Y = \frac{W}{AT} \qquad \text{[Eq 5]}$$

where:

Y = filter yield in dry solids produced per unit area per hour (lb/sq ft/hr)
W = weight of dry cake formed (lb)
A = area of filter (sq ft)
T = total cycle time (hr).

The total cycle time includes time submerged, drying time, and cake removal time.

The experimental filter yield should be investigated for various sludge-conditioning techniques or vacuum filter operating modes to optimize design and/or operation.

Capillary Suction Time (CST) Test

This test is one of the fastest and simplest to perform in assessing the dewatering characteristics of sludges. The results are useful for comparing conditioning methods or as an operator's tool in determining polymer dose for full-scale dewatering devices. The CST test is run on the apparatus shown in Figure 5. Sludge samples are conditioned by mixing with known concentrations of polymer or other conditioner. The sample is then poured into the tube of the CST apparatus. As sludge is dewatered, liquid flows outward through special blotter paper. The time required for the liquid to flow 0.38 in. is measured.

Tests to determine the dewatering characteristics of sludges are described in greater detail in a manual available from the American Water Works Association Research Foundation, as are jar test methods for preparing the sludge for these tests.[41]

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[40] D. A. Cornwell et al.

[41] S. K. Dentel et al., "Selecting Coagulant, Filtration, and Sludge Conditioning Aids," *JAWWA* (January 1988).

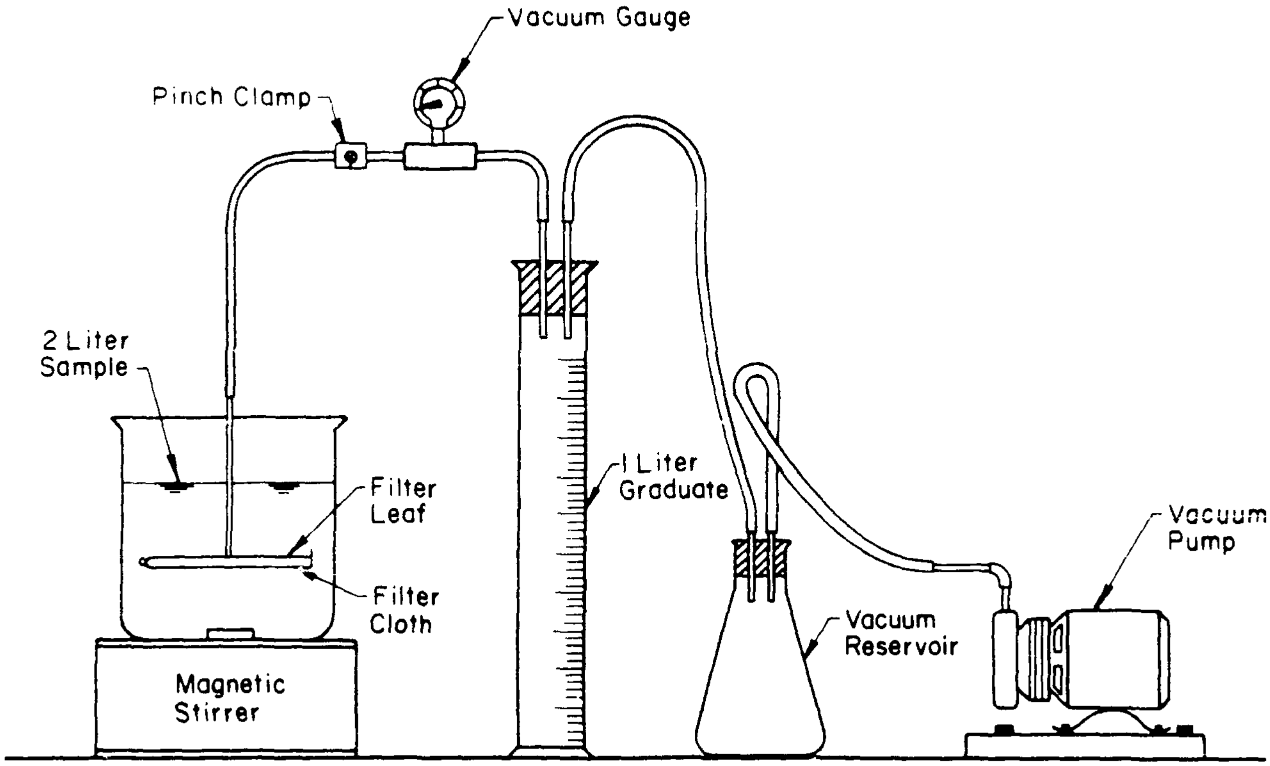

Figure 4. **Leaf test apparatus.** (Source: D. A. Cornwell et al., *Water Treatment Plant Waste Management* [AWWA Research Foundation, June 1987]. Used with permission.)

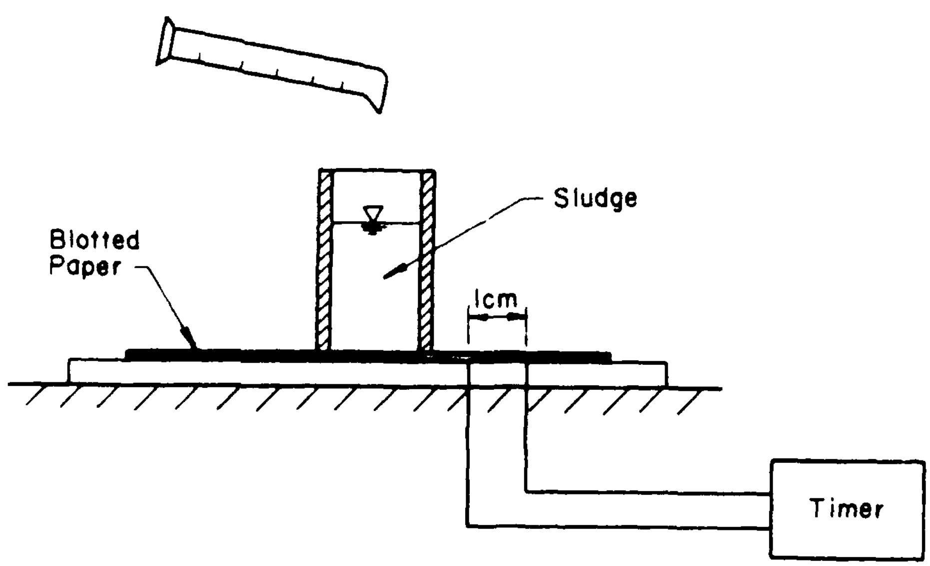

Figure 5. Capillary suction time (CST) apparatus.

It is important in using the jar test to simulate as closely as possible the conditions in the treatment plant, including detention time, mixing intensity, temperature, pH, and order of addition for all chemicals.

Chemical Characteristics

The major constituent of all water plant wastes is water. Knocke and Wakeland[42] classified the water content of wastewater sludges into four categories:

1. Free water is not held to sludge solids and can be removed by simple gravitational settling.

2. Floc water is trapped within sludge flocs and can be removed by mechanical dewatering.

3. Capillary water is held to sludge solids by surface tension and attractive forces and can be removed only by compaction and deformation of the sludge flocs.

4. Bound water is chemically bound to the individual floc particle and cannot be removed.

For chemical sludges, three classifications have been proposed:[43]

1. Free water can be removed by draining or low-pressure mechanical methods.

2. Hydrogen-bound water is attracted to the floc particle through hydrogen binding. The attractive force of the water to the chemical floc is in the range of 0.13 kcal/mole.

3. Chemically bound water is bound through covalent bonds directly to the chemical floc.

Aluminum and iron coagulation result in flocs of the form $Al(OH)_3 \cdot 3H_2O$ and $Fe(OH)_3 \cdot 3H_2O$. In the case of aluminum, the chemically bound water is about 40 percent. Therefore, mechanical devices could not dewater sludge predominant in the chemical hydroxide flocs to greater than a 60 percent solids concentration and, in practice, dewatering is limited to achieving a 45 to 50 percent solids concentration. As the sludge ages, the floc will slowly equilibrate to the oxide form (Al_2O_3 or Fe_2O_3) and solids concentrations up to 90 percent can be achieved.

Low-pressure mechanical devices do not have enough energy to overcome hydrogen binding. Thus, centrifuges, vacuum filters, and belt presses will remove only the free water and the water physically trapped within floc particles.

Concern for safe disposal of sludges has increased awareness of the chemical sludge constituents. Table 6 summarizes the finding of a literature search on alum sludge characteristics conducted by Given and Spink.[44]

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[42] W. R. Knocke and K. L. Wakeland.

[43] D. A. Cornwell et al.

[44] P. W. Given and D. Spink, "Alum Sludge: Treatment Disposal and Characterization," *Proceedings, 36th Annual Western Canada Water and Sewage Conference* (September 1984).

Table 6

Reported Alum Sludge Characteristics

Parameter	Concentration
Total solids (TS)	0.1 to 27% by weight
Volatile solids	10 to 35% of total solids
Suspended solids	75 to 99% of total solids
pH	5.5 to 7.5
BOD	30 to 6000 mg/L
COD	500 to 27,000 mg/L
Aluminum (limited data)	4 to 11% of TS as Al
Iron	6.5% of TS (one sample)
Manganese	0.005 - 5% of TS
Arsenic	0.04% of TS
Cadmium	0.005% of TS
Individual heavy metals	0.03% of TS
Total Kjeldahl nitrogen	0.7 to 1,200 mg/L as N
Phosphate	0.3 to 300 mg/L as P
Total plate count	30 to >300,000/mL

Softening sludges generally have low BOD and COD. The chemical constituents of the sludge vary with the composition of the raw water and the chemicals added. Table 7 presents the results of chemical analyses of dry solids from eight water-softening plants.

Softening sludges should be analyzed periodically for excess lime, and the calcium-to-magnesium (Ca:Mg) ratio calculated. Excess lime is an indicator of incomplete reaction in the softening process. If CaO or $Ca(OH)_2$ is present in the solid phase, it is an indication of poor dissolution, which increases chemical costs. If the lime does not dissolve prior to incorporation into the sludge, it might remain as $Ca(OH)_2$, thus causing poor dewaterability and ultimately an increase in the amount of sludge. Corrective action should be taken to eliminate these conditions.[45]

A sludge's Ca:Mg ratio is an indicator of its ability to thicken and dewater. Generally, a sludge with a Ca:Mg ratio less than 2:1 will be difficult to dewater, whereas one with a Ca:Mg ratio greater than 5:1 will dewater relatively easily.[46] Figure 6 is a plot of Ca:Mg molar ratio versus the settled solids concentration and filter cake solids concentration. Similarly, a high magnesium content in lime sludges adversely affects the specific resistance, as shown in Figure 7. High-magnesium softening sludges can be considered to be nearly equal to mixed coagulant-softening sludges due to similarly poor dewaterability.

Specific inorganic concentrations are not reported in the literature for lime sludges; however, inorganics will be present to the extent that they are removed from the raw water. Figure 8 is a generalized guide showing inorganic contaminants likely to be removed by lime softening for the indicated pH range.[47] As can be seen, some removal will occur for most of the inorganic contaminants, with high removals for some of the compounds. It is likely that most lime sludges will pass the standard toxicity test for the sludges (EP test) procedure regardless of the concentration of constituent in the sludge. The amount of acid used in the test procedure will generally not lower the pH of lime sludge due to its high buffer capacity and, therefore, metals will not leach.

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[45] AWWA Sludge Treatment and Disposal Committee Report.
[46] R. B. Williams and G. L. Culp.
[47] *Manual of Treatment Techniques for Meeting the Interim Primary Drinking Water Regulations*, EPA 600/18-77-005 [USEPA, April 1978].)

Table 7

Lime Softening Sludge Characteristics for Eight Plants

	Boulder City, NV*	Miami, FL*	Wright Afro Corp., Cincinnati, OH	St. Paul, MN*	Lansing, MI*	Wichita, KS**	Vanderberg, CA‡	Columbus, OH§
	Percent by Weight							
Silica, iron, aluminum oxides	2.6	1.5	4.4	2.0	--	0.6-2.0	7	3.3-3.6
Calcium carbonate	87.2	93.0	88.1	85.0	80-90	89-98	85	80-85
Calcium hydroxide	--	--	--	--	--	--	1	--
Magnesium oxide	7.0	1.8	2.2	6.2	4-6	0.4-3.5	7	5.2-8.6

* Singer, P.C., "Softener Sludge disposal--What's Best," Water and Waste Engineering, p. 25, December 1974.
** Black and Beatch, Report on Water Treatment Plant Waste Disposal, Kansas, December 1969.
‡ Laurence, Charles, "Live Soda Sludge Recirculation Experiments at Vandenberg Air Force Base," JAWWA 55:2:177, 1963.
§ Burris, Michael A., et al., "Softening and Coagulation Sludge--Disposal Studies for a Surface Water Supply," JAWWA, 68(s):247, May, 1976.

(Source: R. B. Williams and G. L. Culp [Eds.], Handbook of Public Water Supply [Van Nostrand Reinhold, 1986]. Used with permission.)

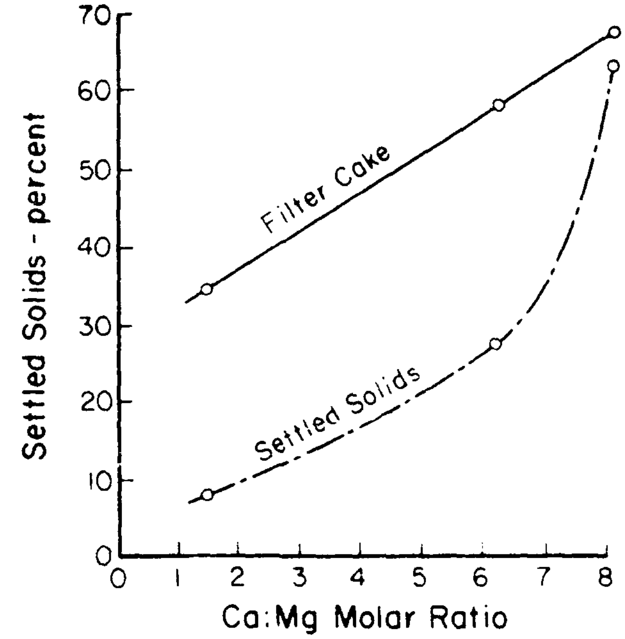

Figure 6. **Effect of Ca:Mg ratio on sludge solids concentration for lime sludges.** (Source: R. B. Williams and G. L Culp (Eds.), *Handbook of Public Water Supply* [Van Nostrand Reinhold, 1986]. Used with permission.)

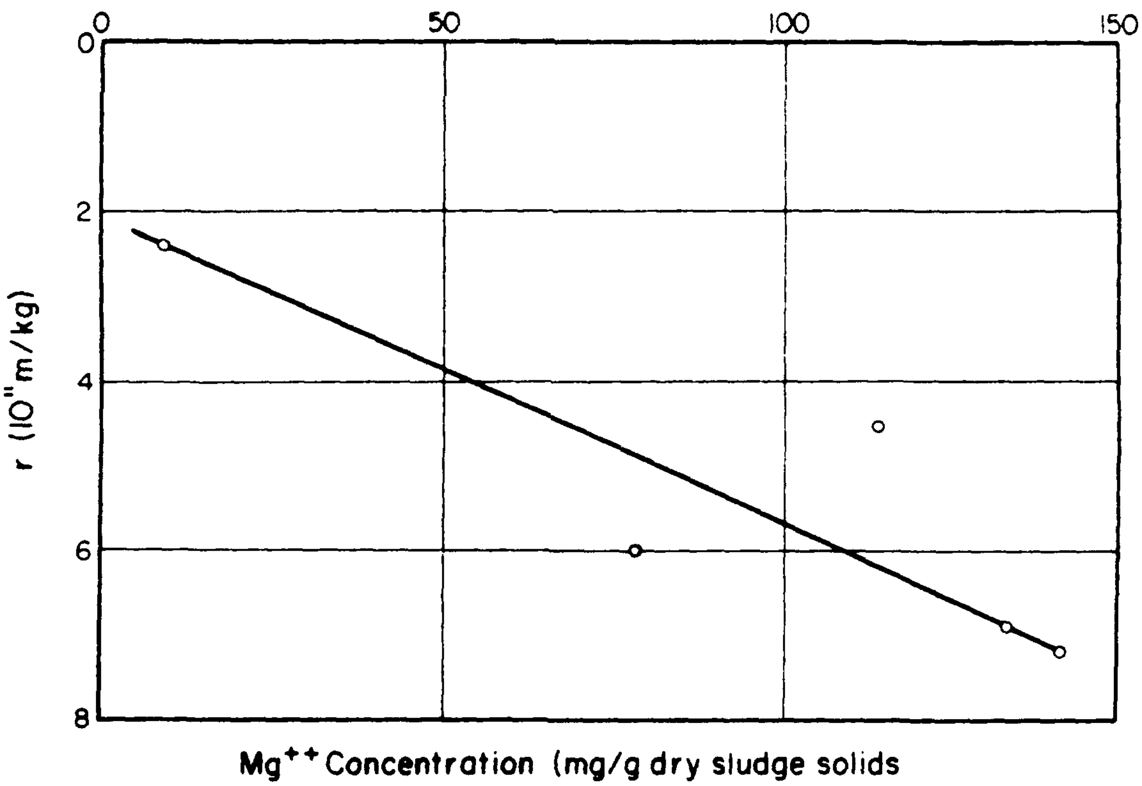

Figure 7. **Effect of magnesium concentration on the specific resistance of softening sludges.** (Source: R. J. Calkins and J. J. Novak, "Characteristics of Chemical Sludges," *JAWWA*, Vol 65, No. 6 [June 1973]. Used with permission.)

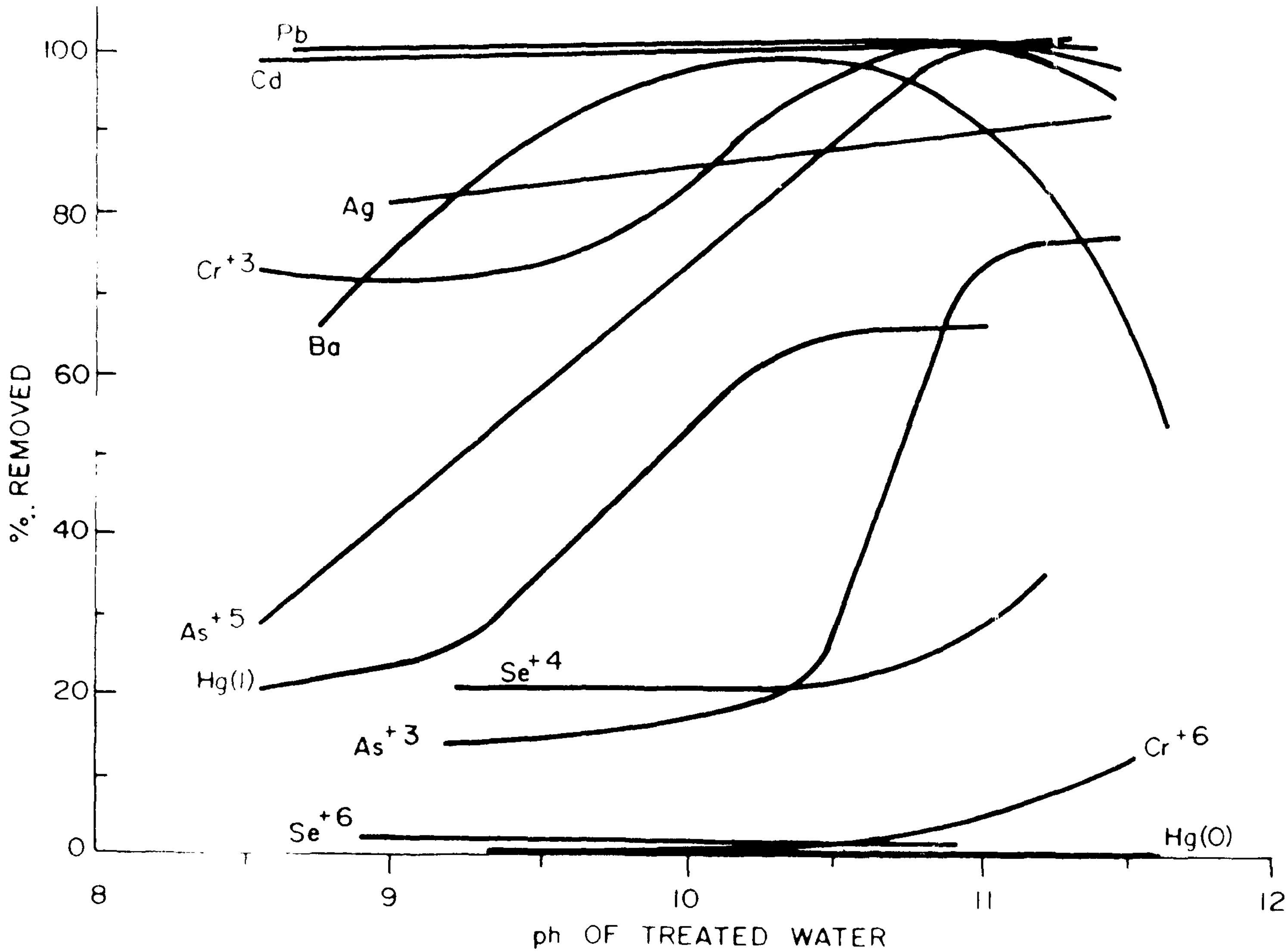

Figure 8. Removal of inorganic contaminants by lime softening. (Source: *Manual of Treatment Techniques for Meeting the Interim Primary Drinking Water Regulations*, EPA 600/18-77-005 [USEPA, April 1978].)

5 WASTE TREATMENT

The treatment of wastes produced by water treatment processes involves separation of water from solids to the degree necessary for the required disposal method. Therefore, the required degree of treatment is a direct function of the ultimate disposal method.

Several treatment methods have been practiced in the water industry. Figure 9 shows the most common sludge handling options available, listed by general categories of thickening, dewatering, and disposal. In choosing a combination of possible treatments, it is probably best to first identify the available disposal options and their requirements for a final cake solids concentration. Most landfill applications will require a "handleable" sludge and this may limit the type of dewatering devices that are acceptable. The goal should not be to simply reach a given solids concentration, but rather to reach a solids concentration of desired properties for the handling, transport, and disposal options available. Table 8 shows a generalized range of results obtained for final solids concentrations from different dewatering devices for coagulant and lime sludges.

As a sludge dewaters, it becomes an increasingly viscous fluid and eventually forms a solid cake. The extent to which a sludge must be dewatered depends on the method of handling. If a sludge is dewatered by vacuum filtration and handled by a conveyor belt, then a lower sheer stress may be sufficient to permit handling than if the sludge is drained on a drying bed and removed from the bed by a loader.[48]

Solids concentration of a dewatered sludge is a poor indicator of its handling ability. Although an alum sludge may be dewatered enough for handling at 30 to 40 percent solids, a lime sludge dewatered in a lagoon to 50 percent solids may not be handleable with earth-moving equipment. Many utilities report that lime sludge cakes in the 50 to 65 percent moisture content range are sticky and difficult to discharge clearly from dump trucks.[49]

Calkins and Novak estimated a relationship between the solids concentration to which a sludge would settle by gravity and the concentration at which the sludge becomes handleable. Figure 10 shows this relationship. Coagulant sludges may only thicken by gravity to a 3 to 4 percent solids concentration and therefore may be handleable at a 20 to 25 percent solids concentration. In contrast, lime sludges may gravity-thicken to a 40 percent solids concentration but not be handleable until a 60 to 70 percent solids concentration is achieved. Often, a 20 percent solids cake is a goal for alum sludges, but transportation constraints may necessitate a higher concentration.

Approach To Handling and Treating Sludge

The approach to handling and treating wastes from water treatment is fourfold:

- Reduce the amount of solids produced
- Dewater and thicken the sludge solids

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[48] J. T. Novak and D. C. Calkins.
[49] R. B. Williams and G. L. Culp.

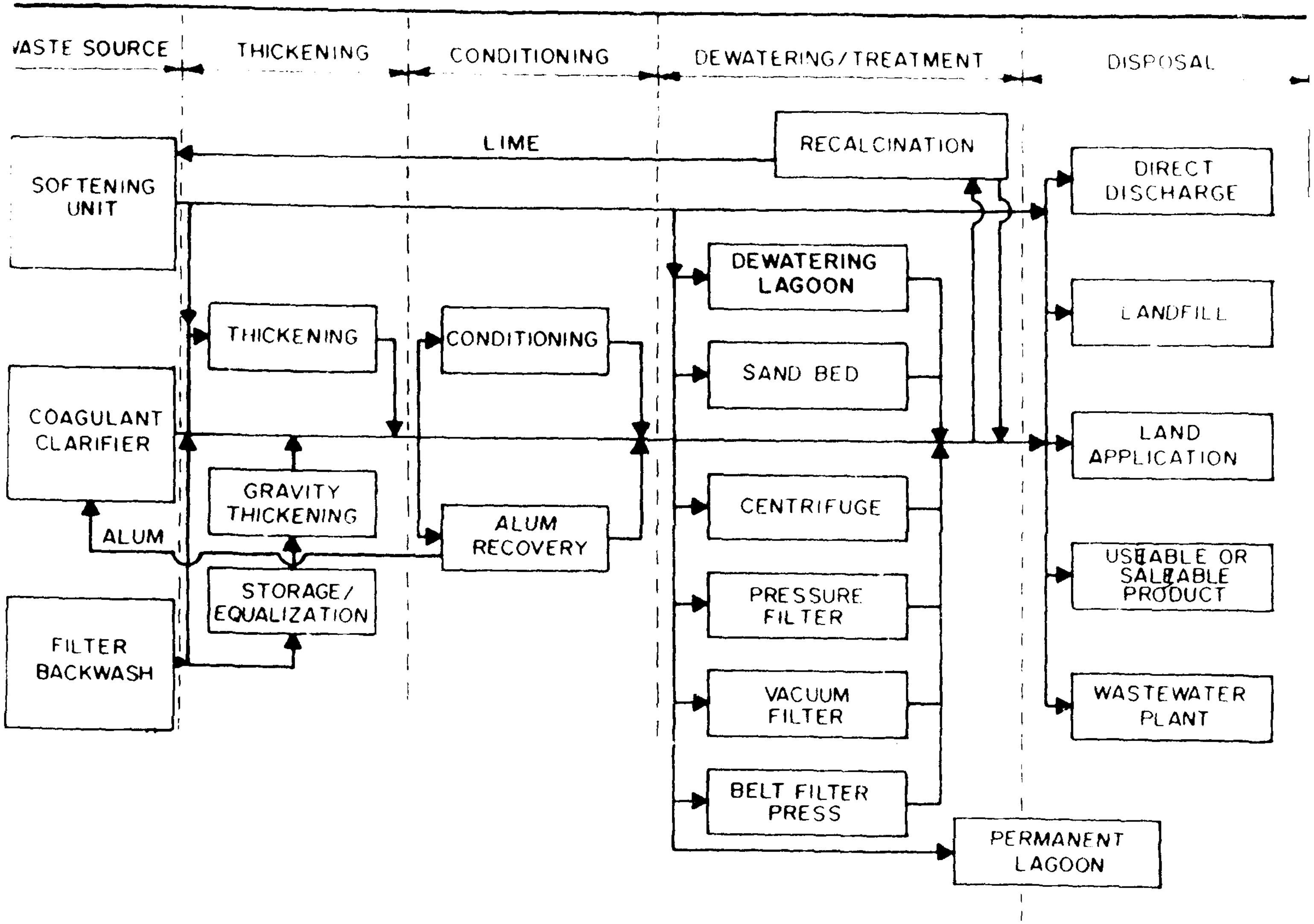

Figure 9. **Sludge handling options.** (Source: D. A. Cornwell et al., *Water Treatment Plant Water Management* [AWAA Research Foundation, June 1987]. Used with permission.)

Table 8

Range of Cake Solid Concentrations Obtainable*

Dewatering Method	Solids Concentration (%)	
	Lime Sludge	Coagulant Sludge
Gravity thickening	15 - 30	3 - 4
Basket centrifuge		10 - 15
Scroll centrifuge	55 - 65	10 - 15
Belt filter press		10 - 15
Vacuum filter	45 - 65	N/A
Pressure filter	55 - 70	35 - 45
Sand drying beds	50	20 - 25
Storage lagoons	50 - 60	7 - 15

*Source: L. E. Lang et al., *Evaluation and Improving Water Treatment Plant Processes at Fixed Army Installations*, Technical Report N-85/10/ADA1../306 (U.S. Army Construction Engineering Research Laboratory, May 1985).

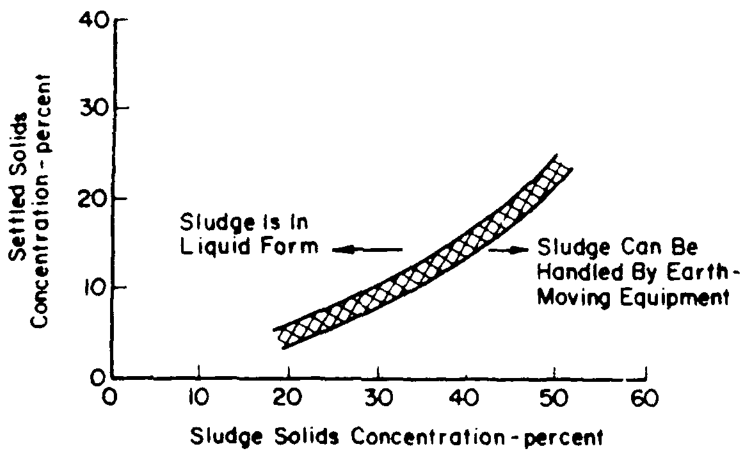

Figure 10. **Solids concentration at which a sludge can be handled.** (Source: R. B. Williams and G. L. Culp [Eds.], *Handbook of Public Water Supply* [Van Nostrand Reinhold, 1986]. Used with permission.)

- Dispose of the solids

- Treat the supernatant.

The most important factors are to reduce the amount of sludge generated and make the sludge easier to dewater. These steps can be done by altering or improving some of the existing treatment processes. Ways of reducing sludge generation and improving dewaterability are discussed below.

Minimizing Sludge Production

Sludge production can be minimized by removing water to reduce the volume, reducing the amount of solids present in the sludge, or both. One method of reducing the amount of solids is to lower the level of chemicals used for coagulation and/or softening. The quantity of chemical coagulant used can be reduced in some plants by substituting polymers for inorganic coagulants, either partially or entirely. However, Bishop has cautioned that polymers are not effective in removing color and create problems in alum recovery processes.[50]

The use of polymers as a possible replacement for alum was assessed in laboratory-scale jar tests in Orange County, NC. The raw water source was a protected reservoir with raw water turbidities between 5 and 50 nephelometric turbidity units (NTU), which contains significant concentrations of organic matter (total organic carbon [TOC] from 6 to 10 ppm). Three coagulants were tested: (1) alum, (2) a cationic polymer with a low molecular weight and a high charge density (polymer A), and (3) a cationic polymer with a high molecular weight and a low charge density (polymer B). Based on these tests, the necessary alum dosage was reduced from 60 to 30 ppm when 0.05 ppm of polymer B was also used. These results indicated that the alum-polymer B combination improved removal of turbidity and TOC, reduced sludge volume, and lowered chemical costs compared with using alum alone. Best results were obtained by adding alum first, followed by the polymer.[51] The use of polymers as primary coagulants and coagulant aids is discussed by Lang et al.[52] and polymer system design is discussed by Amirtharajah.[53]

New and improved coagulant aids continue to be developed. Most plants probably can benefit by a periodic review of the applicability of such aids. As with any change in a treatment process, care must be taken to ensure there will be no degradation in finished water quality or reliability of treatment. It is difficult to measure the suitability of another coagulant based solely on laboratory testing. Often, as the amount of alum is reduced, the most important characteristic of the treated water becomes the floc strength and the proper preparation of the water for filtration. These characteristics can best be tested on a small scale using a pilot filter, or on a controlled basis with plant-scale tests.

[50] S. L. Bishop, "Alternate Processes for Treatment of Water Plant Wastes," *JAWWA* (September 1978).

[51] C. R. James and C. R. O'Melia, "Considering Sludge Protection in the Selection of Coagulants," *JAWWA* (March 1972).

[52] L. E. Lang et al.

[53] A. Amirtharajah, "System Design for Polymer Use," *AWWA Seminar Proceedings, Use of Organic Polyelectrolytes in Water Treatment*, Las Vegas, NV (June 1983).

In softening plants, solids production can be reduced 50 percent by replacing soda ash and some or all of the lime with NaOH. The advantage of this reduction would have to be weighed against the higher cost of NaOH compared with soda ash and lime, however.

Another method of minimizing waste solids production is to reduce the amount of softening if possible. For example, if a plant is removing 150 ppm of hardness, it could reduce its waste solids load by 16 percent by removing only 125 ppm. Not only would the sludge quantity be reduced, but chemical usage costs would decline by a similar amount. The trend in the water industry has often been to soften to 80 ppm. However, few consumers can tell the difference at 100 ppm.[54] Magnesium should be removed to a final value of 40 ppm as $CaCO_3$ hardness because an excessive amount will cause scaling problems. However, reduction of magnesium below this level is seldom justified. The higher the magnesium hydroxide content of the sludge, the poorer its dewaterability, as mentioned earlier.

Split treatment is another method of reducing softening sludge production when high magnesium hardness removals are required. This method eliminates lime treatment of the bypassed water and minimizes recarbonation requirements. It also minimizes sludge production because the calcium carbonate solids created by recarbonation of excess lime are eliminated.[55]

Operators should make sure the chemicals for coagulation and softening are added in the proper dosage and are well mixed in flash mixers and flocculators. Excessive amounts of coagulants are added in many water treatment plants "just to be safe." This tendency results in higher chemical costs and extra solids produced. Based on information from the installation of a pilot filter unit and increased operator awareness, a water treatment plant in New York reduced alum dosage from 17 ppm to 12 ppm without deterioration in finished water quality. Alum usage was reduced by more than 750,000 lb/yr with an estimated decrease in waste sludge generation of about 200,000 lb/yr of dry solids.[56]

Lime sludges often contain unused excess calcium hydroxide, which can be minimized by improved mixing (through proper baffling) or recirculation of sludge. Facilities with well mixed solids contact clarifiers use only 2 to 3 percent excess lime.[57] Sludge recirculation from the clarifier back to the rapid mixer improves the efficiency of calcium carbonate precipitation and reduces excess lime usage. A study at Vandenberg Air Force Base allowed its treatment plant to reduce the excess $Ca(OH)_2$ in the sludge from 5 to 1 percent by weight through sludge recirculation to the flocculation compartment. At the same time, hardness removal efficiency increased by 11 percent.[58] A laboratory study on recycling calcium carbonate sludge to serve as seed crystals for the further

[54]D. A. Cornwell, "Management by Water Treatment Plant Sludges," *Sludge and Its Ultimate Disposal* (Ann Arbor Science, 1981).

[55]R. B. Williams and G. L. Culp.

[56]D. A. Cornwell (1981).

[57]J. E. Singley and T. P. Brodeur, "Control of Precipitative Softening," paper presented at the AWWA Water Quality and Technology Conference (1980).

[58]C. Laurence, "Lime Soda Sludge Recirculation Experiments at Vandenberg Air Force Base," *JAWWA*, Vol 55, No. 2 (1963).

precipitation of hardness from solution showed that sludge dewaterability, as quantified by specific resistance, improved significantly.[59]

Recycling filter backwash and clarified water from the dewatering process will reduce solids load because this water has already been softened. These process wastewaters represent 3 to 5 percent of total plant flow; thus, their recycle would reduce solids loads by a similar amount.[60]

Sludge volumes can be minimized by controlling sludge withdrawals from the settling basins to increase the solids content. By increasing the solids content 2 to 5 percent, the sludge volume would be reduced 60 percent.[61] Similarly, alum sludge volumes may also be reduced, although the increase in solids content may be only from 0.5 to 0.75 percent since alum sludges are much more dilute than calcium carbonate sludges.[62]

Direct filtration can be used where the raw water supply is of high quality. This process has lower chemical feed rates than conventional flocculation, settling, and filtration, and therefore produces less sludge.

Sludge Thickening

Thickening, which begins with concentrating the sludge in the bottom of the clarifier, is an effective, inexpensive method and generally the first phase of reducing sludge volume and improving sludge dewatering characteristics. Thickening, however, is done most effectively as a separate operation. Thickening tanks can also serve as equalization facilities to provide a uniform feed to the dewatering step.

Gravity sludge thickeners are generally circular settling basins equipped with either a scraper mechanism in the bottom or sludge hoppers. They may be operated as continuous flow or as batch fill and draw thickeners. Figure 11 shows a continuous flow gravity thickener.

Cost curves for gravity thickeners are presented in Figures 12 and 13. Figure 12 is a capital cost curve. Thickener capital costs include the costs for the scraper mechanism and its installation and for the circular reinforced concrete basin and appurtenances. Effluent troughs, inbound weir baffles, center support column, steel half-span bridge, typical excavation and site work for the basin, and electrical work required for operating the equipment are also included.

O&M costs are shown in Figure 13. These costs include energy costs relative to the process scraper mechanism only and do not take into account the sludge pumping or chemical costs. The maintenance materials cost is for repair and replacement of the scraper mechanism and weir. Labor costs are for normal O&M of the process.

A description of how these cost curves were derived is found in Appendix A of *Water Treatment Plant Waste Management Handbook.*[63] The costs were current for June 1986, and the curves are accurate for a study phase involving paper screening of

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[59]J. F. Judkins, Jr., and R. H. Wynne, Jr. "Crystal-Seed Conditioning of Lime Softening Sludge," *JAWWA*, Vol 64, No. 5 (1972).

[60]AWWA Sludge Treatment and Disposal Committee Report.

[61]AWWA Sludge Treatment and Disposal Committee Report.

[62]R. B. Williams and G. L. Culp.

[63]D. A. Cornwell et al. (June 1987).

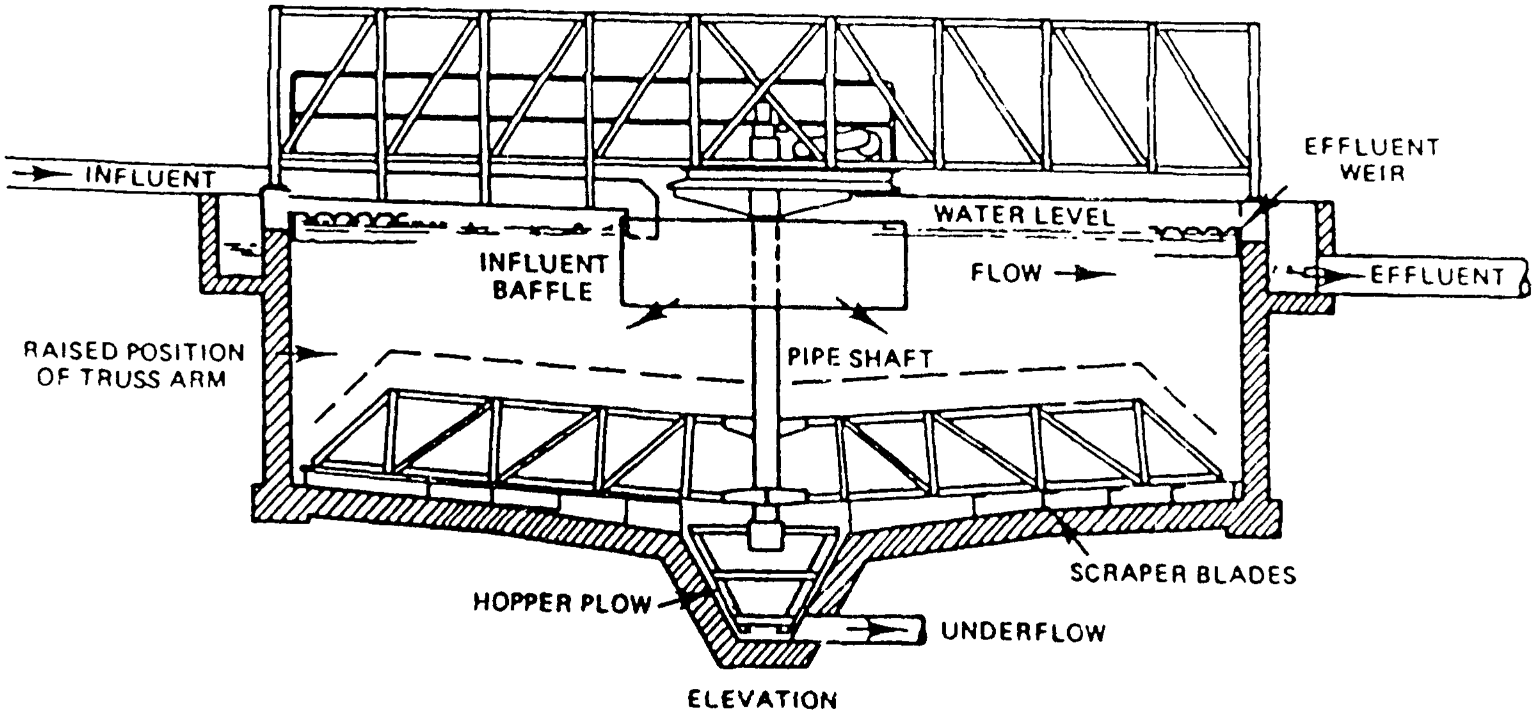

Figure 11. Continuous flow gravity thickener. (Source D.A. Cornwell et al., Water Treatment Plant Waste Management [AWWA Research Foundation, June 1987]. Used with permission).

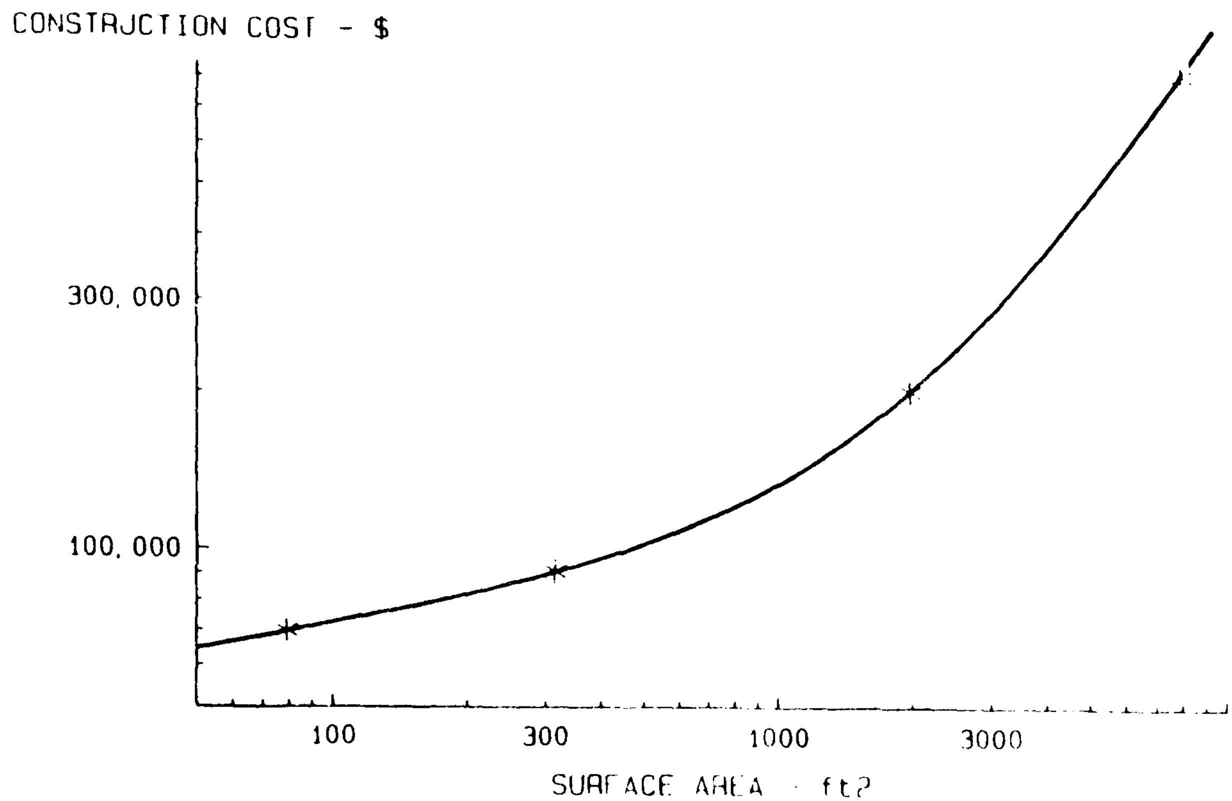

Figure 12. **Construction cost for gravity sludge thickeners.** (Source: D. A. Cornwell et al., *Water Treatment Plant Waste Management* [AWWA Research Foundation, June 1987]. Used with permission.)

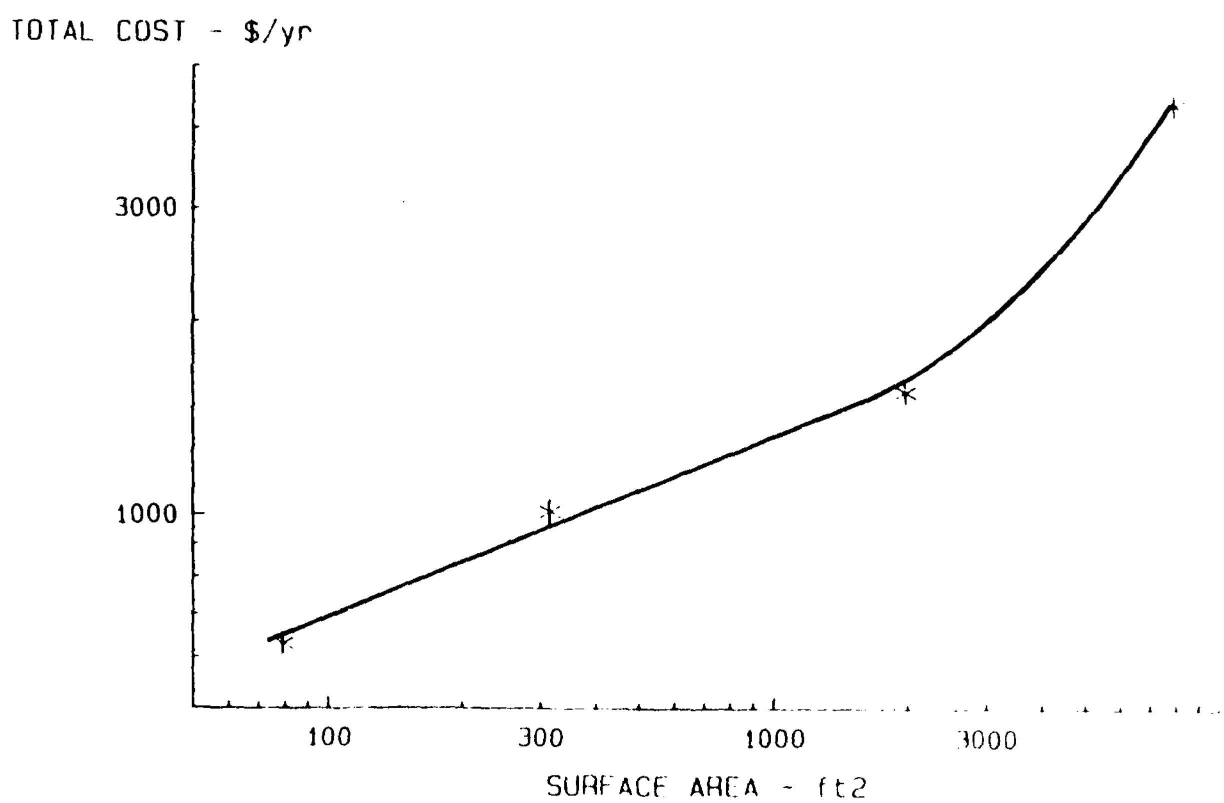

Figure 13. **Operation and maintenance cost for gravity sludge thickeners.** (Source: D. A. Cornwell et al., *Water Treatment Plant Waste Management* [AWWA Research Foundation, June 1987]. Used with permission.)

alternatives. As the evaluation moves to a pilot phase or preliminary design, site-specific costing is needed. The *Engineering News Record (ENR)*, Construction Cost Index (CCI), and Building Cost Index can be used to update construction and building costs.

Coagulant Sludge Thickening Results. Typical design parameters reported for alum sludge thickening are 100 to 200 gal/sq ft/day when sludges are conditioned with polymers. Polymers have minimal effect on the ultimate degree of compression, but affect particle size and zone settling velocity and will likely improve capture efficiency. Alum sludges mixed with clay or lime have exhibited thickened concentrations of 3 to 6 percent and 9 percent, respectively, at higher overflow rates than sludges without clay or lime addition.[64]

Lime Sludge Thickening Results. Solids loadings of 60 to 200 lb/sq ft of thickener surface area/day are commonly practiced.[65] Solids output can range from 15 to 30 percent. Bench-scale thickening tests should be performed to estimate sludge thickening characteristics and design requirements. Storage requirements must be considered when designing a thickener, particularly when a dewatering device is used.

Sludge Conditioning

Water sludge conditioning refers to the variety of chemical and physical techniques for altering sludge characteristics to make subsequent removal of water more efficient. There are no clear-cut, accepted conditioning methods for the different types of sludge. A conditioning agent that works well at one plant may not work at a similar plant. Sludge properties used for evaluating different conditioning agents include specific resistance, coefficient of compressibility, and capillary suction time (as discussed in Chapter 4).

Generally, only hydroxide sludges and backwash wastes need to be conditioned. Lime-softening sludges are seldom conditioned because they are more easily dewatered. With hydroxide sludges, conditioning agents are used either to assist in water/solids separation or to affect compressibility and minimize media clogging, such as in filter press operation. Polymers are usually used for water removal processes, and lime has traditionally been used to prevent media clogging, although polymers have recently been used successfully for this purpose.[66]

Polymers vary in structural composition, molecular weight, and charge density. For most cationic polymers, the charge density is near 100 percent and their molecular weight is generally less than anionic or nonionic polymers. Anionic polymers vary in both charge density and molecular weight. Nonionic polymers have no charge density, but have high molecular weights.[67] In general, for hydroxide sludge conditioning, the higher the molecular weight of polymers with long carbon chain lengths, the smaller the dose required for conditioning, but the more likely polymer handling problems. Molecular weight may even be more important than the charge type or density.[68]

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[64] R. B. Williams and G. L. Culp.
[65] R. B. Williams and G. L. Culp.
[66] D. A. Cornwell et al. (June 1987).
[67] D. A. Cornwell et al. (June 1987).
[68] J. T. Novak and J. O'Brien, "Polymer Conditioning of Chemical Sludges," *Journal of the Water Pollution Control Federation*, Vol 47, No. 10 (1975).

Polymer addition is usually necessary for dewatering hydroxide sludges by either nonmechanical or mechanical methods. It appears that the primary mechanism is interparticle bridging such that the polymers form a porous matrix that permits water decanting or drainage. It is thought that the polymer does not alter the chemical structure of the hydroxide particles themselves.[69]

When first selecting a polymer type, a series of screening tests is needed. Usually, manufacturers will provide or sell at low cost sample polymers that they think will work for the particular application. To determine comparative doses, either the CST test or the specific resistance test can be used. Results of these two tests generally correlate well, but the CST test method is superior in terms of required analysis time, variability of results, and required analytical expertise.[70] Figure 14 shows one comparative plot for the effect of polymer type and dose on the conditioning of an aluminum hydroxide sludge.

When performing the jar tests to prepare sludge for the screening test, it is important to establish conditions similar to operating conditions in terms of temperature, pH, and mixing time and intensity. If a high-stress mechanical dewatering process is to be used, then high-intensity mixing should be employed to simulate this process. The most significant parameter has been shown to be total mixing energy input (Gt) which is the product of velocity gradient (G) and mixing time (t).[71] For a given polymer dose, any combination of G and t, within a range of G and t values, that gives the optimal Gt value will result in sludge with similar dewatering characteristics. Polymer requirements generally increase as Gt increases,[72] so the optimal dose determined during low-stress testing may be inadequate under high-stress dewatering processes. Polymer selections also become more important as Gt increases. Excessive mixing causes sludges floc deterioration that is irreversible. These screening tests can be valuable in selecting polymers and estimating doses, but some full-scale plant testing is still required.

Once the optimal polymer and dosage are selected, the purchase should be bid competitively. Even if the polymer to be used is specified, manufacturers will generally want to bid what they consider to be an equal product. Bids should specify dollars versus performance such as the cost of treating 650 tons/yr and the polymer must attain a CST of 7. This factor is needed because often a given polymer may cost twice as much per pound but reach the optimal conditioning at one-third the dose.[73]

Figures 15 through 18 are cost curves for lime and polymer feed conditioning.[74] The construction costs for the polymer feed system are shown in Figure 15. Capital costs developed for polymer feed systems are based on feeding dry polymer directly to a storage hopper on a chemical feeder. The system is sized based on a 0.5 percent stock solution and 30 min of aging. Piping, valves, instrumentation, and a standby polymer feed pump are all included.

O&M costs for the polymer feed system are shown in Figure 16. The O&M costs include the energy requirements for the feeder and metering pump, maintenance material costs, and system labor. Polymer cost was not included since pricing for the numerous polymers available is so variable.

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[69]W. R. Knocke and K. L. Wakeland.
[70]S. K. Dentel et al.
[71]C. P. Werle et al., *Journal of Environmental Engineering, ASCE*, Vol 110, No. 5 (1984).
[72]J. T. Novak et al., *Journal of Electrical Engineering, ASCE*, Vol 114, No. 1 (1988).
[73]D. A. Cornwell et al. (June 1987).
[74]D. A. Cornwell et al. (June 1987).

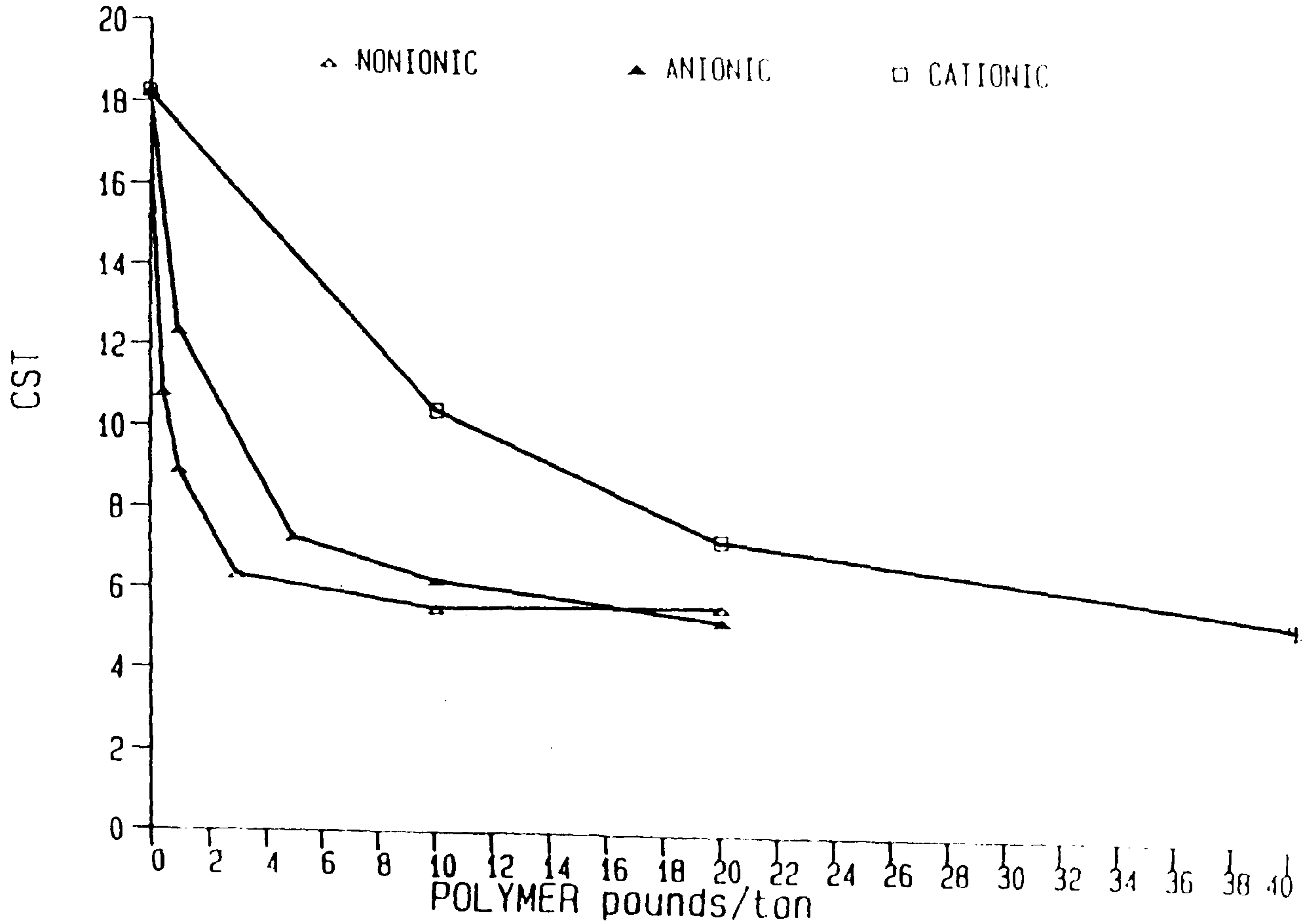

Figure 14. CST versus polymer dosage. (Source: D. A. Cornwell et al., *Water Treatment Plant Waste Management* [AWWA Research Foundation, June 1987]. Used with permission.)

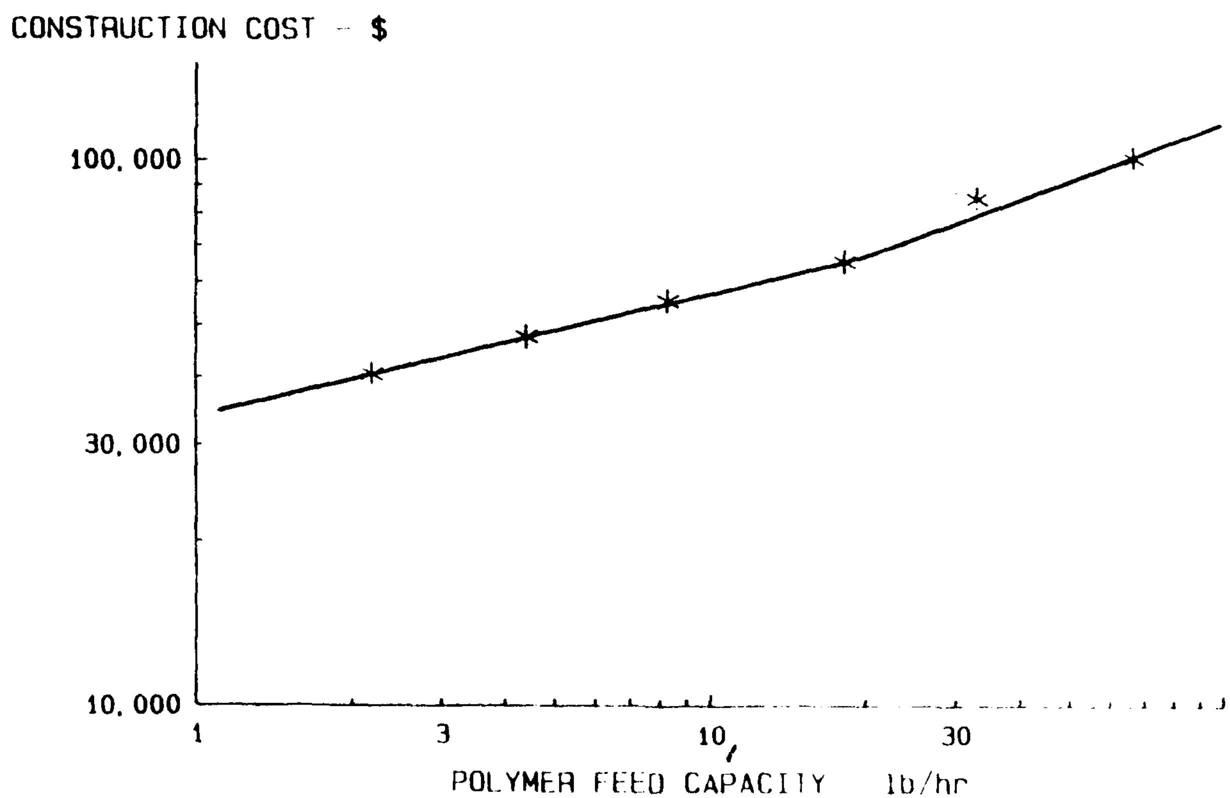

Figure 15. Construction cost for polymer feed systems. (Source: D. A. Cornwell et al., Water Treatment Plant Waste Management [AWWA Research Foundation, June 1987]. Used with permission.)

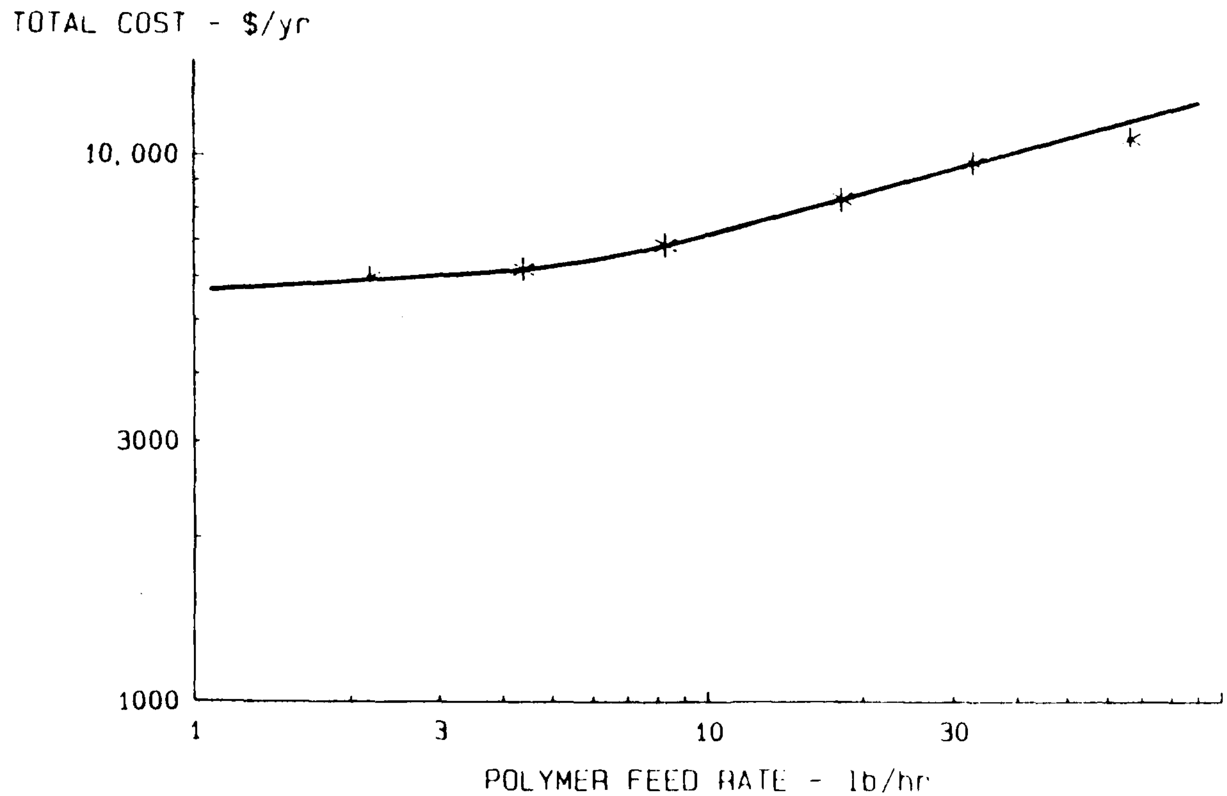

Figure 16. Operation and maintenance cost for polymer feed systems. (Source: D. A. Cornwell et al., *Water Treatment Plant Waste Management* [AWWA Research Foundation, June 1987]. Used with permission.)

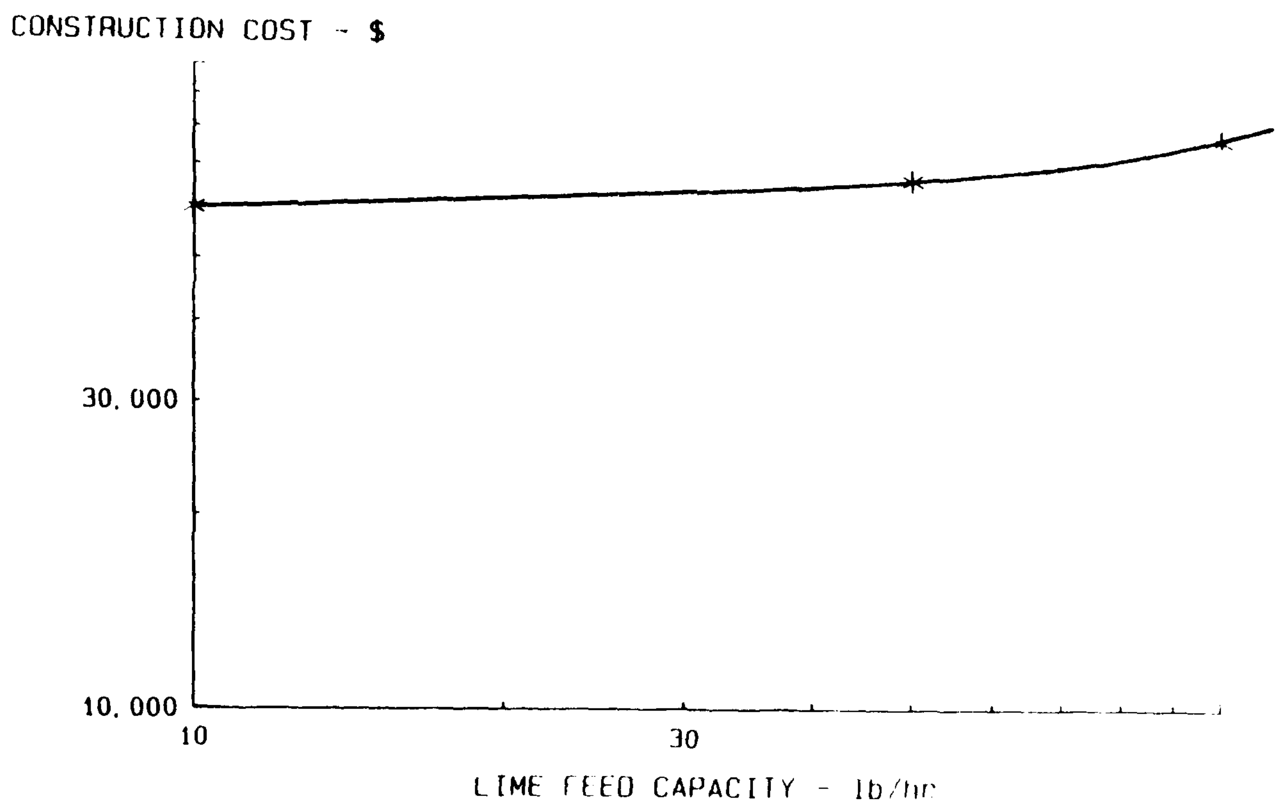

Figure 17. Construction cost for lime feed systems. (Source: D. A. Cornwell et al., *Water Treatment Plant Waste Management* [AWWA Research Foundation, June 1987]. Used with permission.)

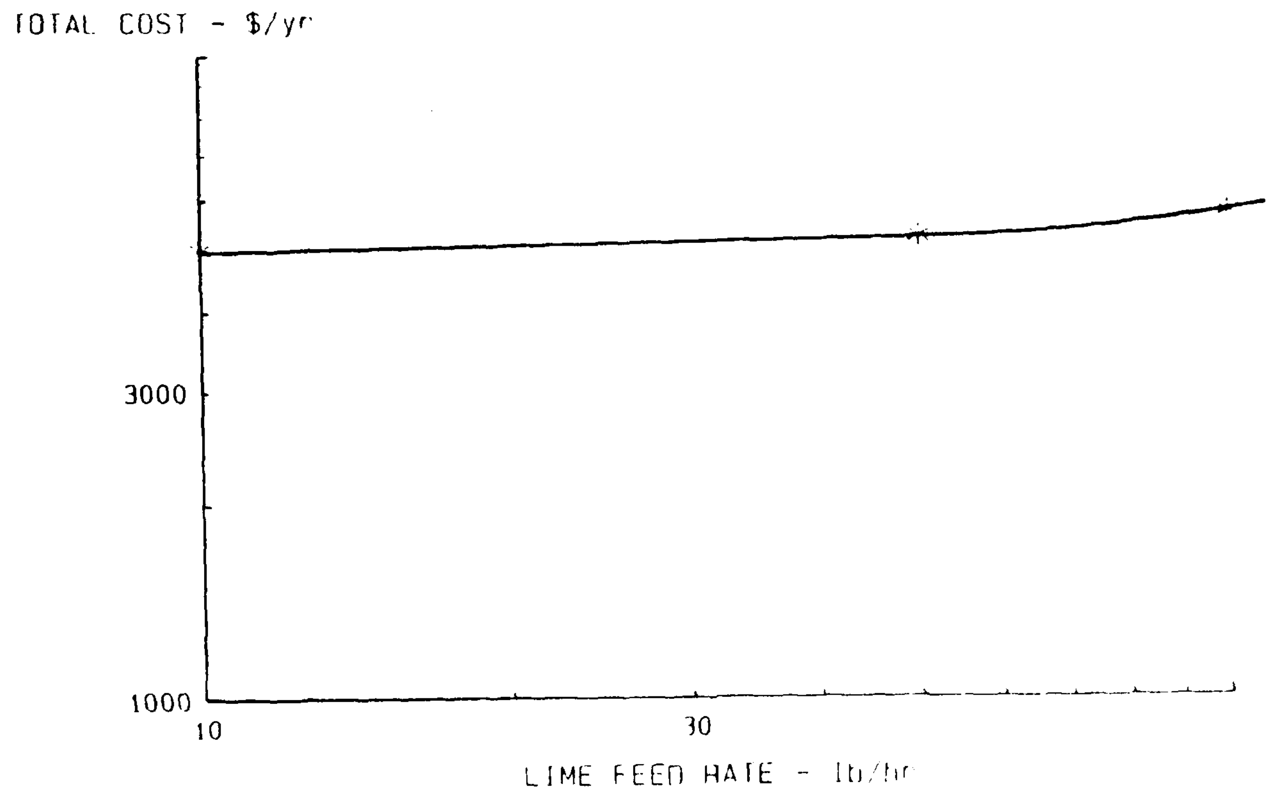

Figure 18. Operation and maintenance cost for lime feed systems. (Source: D. A. Cornwell et al., *Water Treatment Plant Waste Management* [AWWA Research Foundation, June 1987]. Used with permission.)

Liquid polymer systems are generally comparable in cost to dry polymer systems. Due to higher chemical purchase costs and increased horsepower, the O&M costs for the liquid system are usually higher but the capital cost is usually lower.

Figure 17 shows construction costs for a hydrated lime feed system. The system includes lime storage, dual feeder solution tanks with mixers, and dual metering pumps. The storage hopper was provided with dust collectors and sized for 1 day of lime storage.

O&M costs for lime feed systems (Figure 18) include energy for the mixers and metering pumps, maintenance materials costs, and labor costs, which were based on manufacturers' recommendations and experience. The cost of lime was not included.

Sludge Dewatering

Sludge can be dewatered by a number of different processes, as discussed below. Table 9 summarizes the characteristics of these processes.

Nonmechanical Dewatering

The nonmechanical dewatering methods most feasible for Army plants are lagoons, sand drying beds, and freezing.

Lagoons. Lagoons are a very common treatment for dewatering sludge. One survey showed that 56 percent of water treatment plants with softening used them.[75] Of those utilities having lagoons, 60 percent used them for permanent sludge disposal; 32 percent used them to thicken sludge to 30 to 60 percent solids before dredging it to spread on farmland or mix with landfill; and 8 percent used the lagoons for dewatering, with dried cake applied to farmland.

Storage lagoons typically are earthen basins with 4- to 12-ft sidewater depths, covering from 0.5 to 15 acres which are equipped with inlet control devices and overflow structures. Sludge is added until the lagoon is filled with solids and then it is removed from service until the solids have dried to the point at which they can be removed for disposal, if in fact the sludge can dewater to this point.

Alum sludges have proved difficult to dewater in lagoons to a concentration at which they can be landfilled. Some plants have reported removing thickened alum sludge by dragline or clamshell and dumping it in thin layers on the lagoon banks to air-dry; others have dumped the thickened sludge on land disposal areas or transported it to a specially prepared drying bed.

Lagoons can be constructed for storage or dewatering. Storage lagoons generally have decant capabilities but no underdrain system. They are constructed with sealed bottoms to protect the groundwater. Once the lagoon is full or the decant can no longer meet discharge limitations, it must be abandoned or cleaned. To facilitate drying, standing water can be removed by pumping, leaving a wet sludge. Coagulant sludges can be expected to reach only a 7 to 10 percent solids concentration in storage lagoons. The remaining solids must be either cleaned out wet or allowed to evaporate. Evaporation can take years, depending on the depth of the solids. The top layers will often form a crust preventing the evaporation of the bottom layers.

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[75] AWWA Sludge Treatment and Disposal Committee Report.

Table 9

Summary of Sludge Dewatering and Thickening Methods

Treatment Method	Dewatering (D) or Thickening (T)	% of Solids in Thickened Sludge	Other Treatment Needed	Operator Attention Needed	Amount of Polymers Needed	Relative Cost	Comments
Lagoons	T or D	50%	Could be followed by dewatering.	Low	Optional to improve dewatering.	Low	Softening sludges dewater more easily.
Sand drying beds	T or D	50%	Could be prethickened or followed by dewatering.	Low	Optional to improve seepage, evaporation.	Low	(See lagoons)
Freezing	D	20% after filtering, 70% after draining.	Thicken first 2 to 4% solids. Dewater or filter afterward.	Medium	No	Medium	More effective for alum sludges.
Belt press	D	12-20% alum sludge, 40% softening sludge.	Prethicken	High	Optional	Very High	New application for water treatment plants.
Filter press	D	40-60% alum sludge.	Prethicken	High	Optional to improve dewatering.	High	Usually not economical for small plants.

The main difference between a dewatering lagoon and a storage lagoon is that a dewatering lagoon has a sand and underdrain bottom, similar to a drying bed, whereas a storage lagoon does not. Dewatering lagoons can be designed to achieve a dewatered sludge cake. The advantage of a dewatering lagoon over a drying bed is that storage is built into the system to handle peak loads. However, bottom sand layers can blind with multiple loadings; therefore, more surface area is required than with conventional drying beds. Polymer treatment can be useful in preventing this sand blinding.[76]

The basis for dewatering lagoon design is essentially the same as that for sand drying beds. The difference is that the applied depth is higher and the number of applications per year is greatly reduced.

A construction cost curve[77] for a storage lagoon is shown in Figure 19. Construction costs included excavation and sitework, concrete inlet and outlet structures, and pipes and valves. The depth was assumed to be 10 ft. The inlet structure had slope protection but no flow distribution; outlet structures included decant drawoff capability and decant outlet piping/valving. (Normally, if a natural clay layer is not present, costs for a bottom liner would be added.) The costs did not include an underdrain system. The sand drying bed cost curves would be more appropriate than those for lagoons if the lagoon were to be used as a continuous dewatering lagoon with decant and underdrains.

O&M costs for the storage lagoon are not presented because the method of sludge removal depends on the individual design and cake dryness. Any cost analysis should consider how the lagoons will eventually be cleaned and perhaps further dewatered, and the method of solids disposal. These costs can be significant.

When lagoons are built above ground, the berms or dikes should be 10 to 15 ft high and far enough from property lines so that, if necessary, their top elevation can be raised. This process can be done by removing dried sludge from the lagoons for use as embankment material. Lagoon berms for larger plants or those with softening should be about 12 ft wide at the top to facilitate the use of construction equipment for cleaning the lagoon.[78] Two or more lagoons should be provided for alternating use to allow between 6 months and 1 year for decanting, evaporation, and drainage.

<u>Sand Drying Beds</u>. Sand drying beds generally consist of a shallow structure with a 6- to 9-in. layer of sand over a 12-in.-deep gravel underdrain system. Sand sizes of about 0.19 in. are typically used with a uniformity coefficient of less than 5. Excessively coarse sands result in too great a loss of solids in the drying bed filtrate. The gravel underdrain system used is typically 1/8- to 1/4-in. graded gravel overlying drain tiles.[79] Beds can be built either with or without provisions for mechanical removal of the dried sludge, and with or without a roof or a greenhouse-type covering.

In dry climates, shallow earthen basins are used that rely solely on evaporation to separate solids from the water. These basins are similar to lagoons, with the difference being that the depth of sludge application is similar to that used for sand drying beds. Sludge is applied in 1- to 3-ft layers and allowed to dewater. With either drying bed type, sludge storage facilities may be needed for wet periods that prevent effective dewatering.

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[76]D. A. Cornwell et al. (June 1987).

[77]D. A. Cornwell et al. (June 1987).

[78]L. R. Howson, "Sludge Disposal," *Water Treatment Plant Design* (Ann Arbor Science, 1979).

[79]R. B. Williams and G. L. Culp.

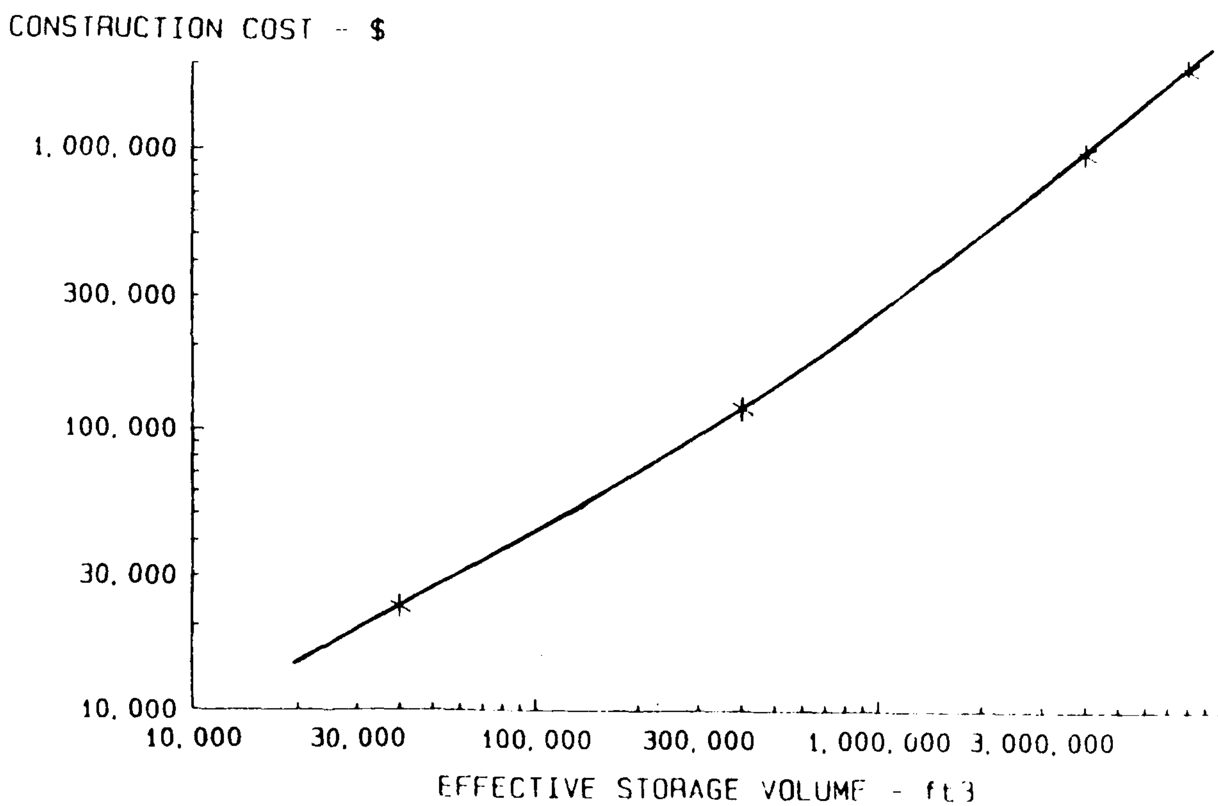

Figure 19. Construction cost for sludge dewatering lagoons. (Source: D. A. Cornwell et al., *Water Treatment Plant Waste Management* [AWWA Research Foundation, June 1987]. Used with permission.)

Several other drying bed designs have been used, including:[39] (1) paved rectangular drying beds with a center sand drainage strip, with or without heating pipes buried in the paved section, and with or without a covering to protect from rain, (2) "wedge-water" drying beds that include a wedge wire septum that allows for an initial flood with a thin layer of water followed by introduction of liquid sludge on top of the water layer, controlled formation of cake, and mechanical cleaning, and (3) rectangular vacuum-assisted drying beds that permit application of vacuum to assist gravity drainage.

The sludge dewatering process occurs by two mechanisms: (1) gravity drainage through the sludge cake and sand filter and (2) air-drying from the surface of the sludge cake by evaporation. The removal of water from sludge by drainage is a two-step process. First, the water is drained from the sludge, into the sand, and out the underdrains. This process may last a few days until the sand is clogged with fine particles or all of the free water has drained away. If beds are provided with a means of removing surface water, further drainage can occur by decanting once a supernatant layer has formed. Decanting can be particularly important with sludges that do not crack for removal of rain. If rain is not removed, it can accumulate on the surface and slow the drying process. The water remaining after initial drainage and decanting must be removed by evaporation.

The method of removing the sludge cake primarily controls the depth of sludge applied to the bed. This depth determines the dried cake thickness at the moisture content that permits the most economical sludge removal. The depth of sludge applied also affects the number of applications per year. The operating costs for sand drying beds are primarily related to the method of removing sludge from the drying beds and include labor, equipment, and sand replacement. Therefore, the most economical operation of a sand bed is the method that minimizes the number of times a bed is cleaned while obtaining the thickness and moisture content of the dried sludge cake that is most economical to remove and providing for the minimal loss of sand.

The *Water Treatment Plant Waste Management* handbook states that the design of a sand drying bed is a function of the:

1. Type of sludge to be dewatered.

2. Solids concentration of the applied sludge.

3. Depth of sludge applied.

4. Amount of water removed by decanting and drainage.

5. Evaporation rate (which is affected by many environmental factors).

6. Sludge removal method used.

7. Ultimate disposal method.

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[39] D. A. Cornwell et al. (June 1987).

All of these factors need to be considered to determine the optimal design loading for a given location, and many are very site-specific. Some of the factors' interrelationships that should be considered are described below:

Sludge Characteristics. The type of sludge to be dewatered can greatly affect the area requirements for sand drying beds. Generally, softening sludges drain rapidly, whereas iron-based coagulant sludges and unconditioned alum sludges show relatively poor drainage characteristics. Chemical treatment with acids and polymers can much improve the dewatering characteristics of alum sludge.

Solids Concentration. The initial dry solids concentration is one of the important factors in determining the size of sand drying beds. For polymer-treated sludges, a higher applied SS concentration is generally associated with a lower bed area requirement.[81]

Depth. For polymer-treated alum sludge, bed size is relatively independent of applied depth.[82] The design consideration for applied depth would thus be the depth of dried cake which is optimal for the removal method and the number of cleanings per year. With a comparatively shallow sludge application, the sludge dries quickly, but there might be such a small amount of dried cake that more labor per unit volume is needed for removal than if the application depth were thicker. More frequent removal can cause increased loss of sand. Therefore, when the wet sludge is applied at a greater depth, a longer time is needed for drying, but the thicker cake can be removed more economically. For sludges with a low specific resistance, drainage can be satisfactory at applied depths of 2 to 3 ft. For poorly draining sludges, applied depths of 1 ft or less are required unless conditioning agents are used.[83]

Decanting and Drainage. Decanting and drainage remove a major portion of the water from sludge on sand drying beds. Evaporation requires a longer time than decanting and drainage. Therefore, the total time that the sludge must remain on the bed is controlled by the amount of water that must be removed by evaporation. Thus, the amount of water removed by drainage and decanting should be maximized.

Inorganic and Organic Constituents. Inorganic constituents such as aluminum, iron, and manganese can influence decisions about recycling the decanted and underdrained liquids from sand beds. Recycling these and other constituents that may be released from the sludge can affect operations in the plant. For example, heavy organic concentrations in the filtrate can cause taste and odor problems, or the recycled liquid may increase production of chlorinated organics

Climate. Sludge dewatering is greatly affected by the regional climate. The drying time is shorter in regions of frequent sunshine, low rainfall, and low humidity. The wind currents also affect evaporation rates.

Alum sludge dewatering can be improved dramatically by the freeze-thaw cycle in cold climates which causes the release of chemically bound water. Provisions for decanting rainwater and the use of polymers are important in areas of heavy rainfall.

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[81] D. A. Cornwell et al. (June 1987).
[82] D. A. Cornwell et al. (June 1987).
[83] R. B. Williams and G. L. Culp.

Drying bed size should be based on the effective number of uses per year and the depth of sludge applied:[84]

$$A = \frac{V}{7.48ND} \qquad \text{[Eq 6]}$$

where:

A = drying bed area (sq ft)

7.48 = constant for use with English units (1000 is the constant for metric units)

N = number of times that beds can be used each year

D = depth of sludge to be applied (ft)

V = annual volume of sludge for disposal (gal).

For example, with a 1 mgd average treated water quantity, 2000 lb of sludge/million gal (MG) treated, and 20 bed uses per year, a 2 percent concentration sludge applied at a 16-in. depth will require:

$$A = \frac{(2000\ \text{lb/MG})(1\ \text{MG/day})\ (365\ \text{day/yr})}{(0.02)(8.34\ \text{lb/gal})\ \dfrac{20\ \text{uses}}{\text{year}}\ \dfrac{16\ \text{in.}}{12\ \text{in/ft}}\ (7.48/\text{gal-cu ft})}$$

$$A = \frac{4{,}376{,}000}{20(1.33)(7.48)} = 22{,}000\ \text{sq ft}$$

Additional design information and methods can be found in *Water Treatment Plant Waste Management.*

The bed is usually considered dewatered when the sludge can be removed by earth-moving equipment (such as a front-end loader) and does not retain large amounts of sand. Alum sludges generally attain solids concentrations of 15 to 30 percent, and lime softening sludges attain 50 to 70 percent solids content.[85] Alum sludges require from 3 to 4 days to drain, but drainage can be accelerated by the use of polymers to 1.5 to 3 days.[86] These times are optimal and do not reflect realistic field conditions. The number of bed uses will range from 10 to 20 times per year, depending on the climate.

Capital and Operating Costs. Construction costs are shown in Figure 20. These costs included excavation and backfill, concrete walls and floor, granular media, pipes and valves, and installation labor.[87] The sand layer was 18 in. thick with a gravel supporting layer and underdrain media. The feed pipe was 6-in. ductile iron piping. The underdrains were 6-in. perforated polyvinyl chloride (PVC) pipe. The collection piping was 6-in. PVC for the 2000-sq ft bed and 12-in. PVC for 6300 sq-ft and larger beds.

[84] R. B. Williams and G. L. Culp.
[85] R. B. Williams and G. L. Culp.
[86] J. T. Novak and M. Langford, "The Use of Polymers for Improving Chemical Sludge Dewatering on Sand Beds," *JAWWA*, Vol 69 (1977).
[87] D. A. Cornwell et al. (June 1987).

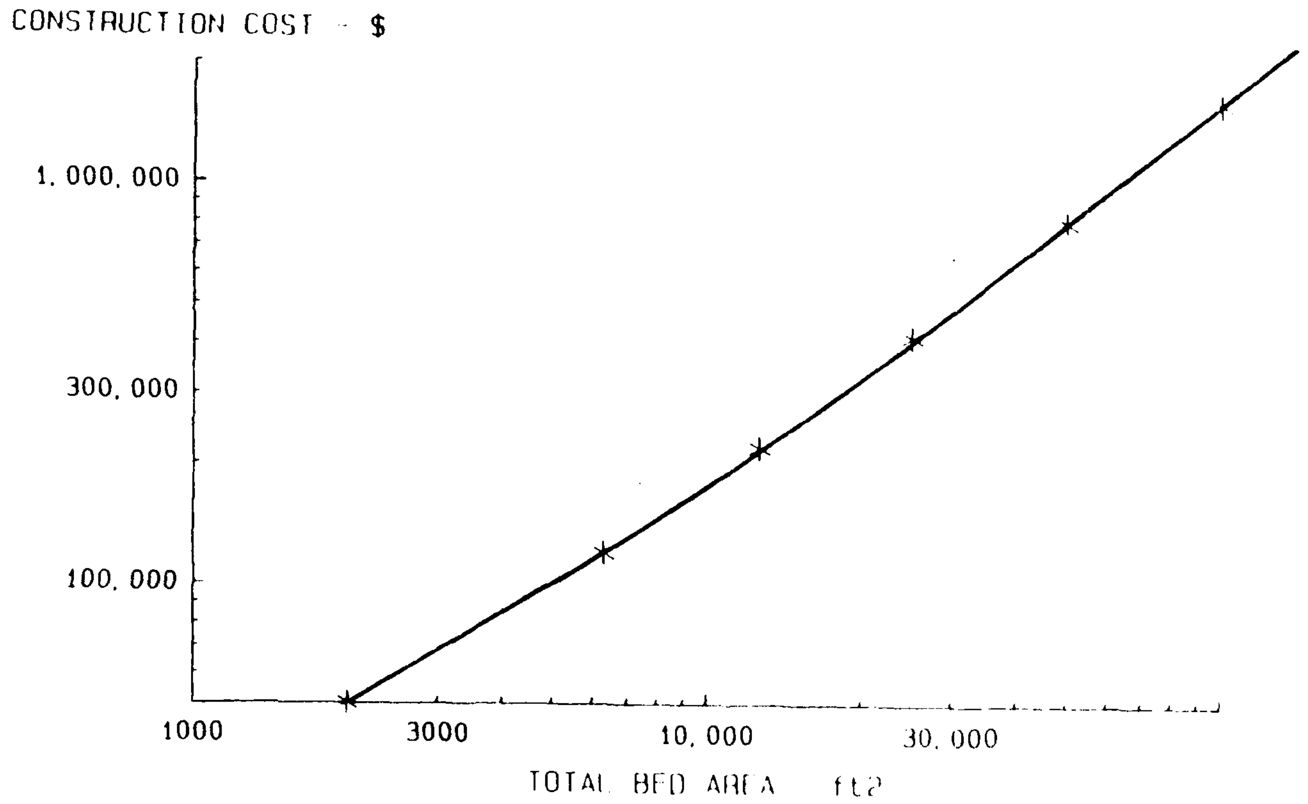

Figure 20. **Construction cost for sand drying beds.** (Source: D. A. Cornwell et al., *Water Treatment Plant Waste Management* [AWWA Research Foundation, June 1987]. Used with permission.)

Figure 21 shows O&M costs. All O&M costs are for removal of dried cake from the beds and bed preparation for the next application of sludge. The fuel costs are for a front-end loader. Maintenance material costs were calculated by assuming that 0.25 in. of sand was to be replaced 20 times per year.

Many plants now use mechanical removal equipment consisting of either front-end loaders or truck-mounted vacuum removal systems, thereby minimizing labor requirements. The dry cake thickness and moisture content should be optimized due to the high cost of operating mechanical removal equipment. Generally, a dry solids content of 15 to 25 percent is sufficient for mechanical removal of alum sludges.

The CST and time-to-filter tests can be used for comparative evaluation of polymer type and dosage. Optimal dosages should be determined carefully, because both under- and overdosing can hamper their effectiveness. The sludge bed loadings for chemically treated and untreated beds should be compared in bench tests and under actual field conditions. Sand blinding may result if excessive amounts of chemicals are used.[88]

Freezing

Freeze-thaw dewatering of alum sludges is generally a modification of sand bed or dewatering lagoon drying, although freezing may be done by mechanical refrigeration. Freezing of waste alum solids causes water in the gelatinous material to crystallize and, upon thawing, the water does not return to the sludge, but leaves a granular solid of coffee-ground consistency. However, the electrical energy cost of artificial freezing is generally prohibitive ($85/ton at $0.05/kWh).[89]

In a natural freeze-thaw system, the sludge is collected in a lagoon or on a drying bed. Ideally, the lagoon should have underdrains. As much water is removed as possible. The sludge is then allowed to freeze in the winter and thaw in the spring. The water released by the freeze-thaw cycle is removed through the underdrains or is decanted. If required, rain and snow can be eliminated by construction of a roof cover. Freezing must take place before a snow cover.

The potential advantages of a freeze-thaw lagoon system are:[90]

1. It is insensitive to variations in sludge quality.

2. No conditioning is required.

3. Minimal operator attention is needed.

4. It is a natural process in cold climates.

5. A solids cake is more acceptable to landfills than more liquid sludges.

6. Sludge is easily worked with conventional equipment.

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[88] D. A. Cornwell et al. (June 1987).

[89] J. H. Wilhelm and C. E. Silverblatt, "Freeze Treatment of Alum Sludge," *JAWWA*, Vol 66 (1976).

[90] D. A. Cornwell et al. (June 1987).

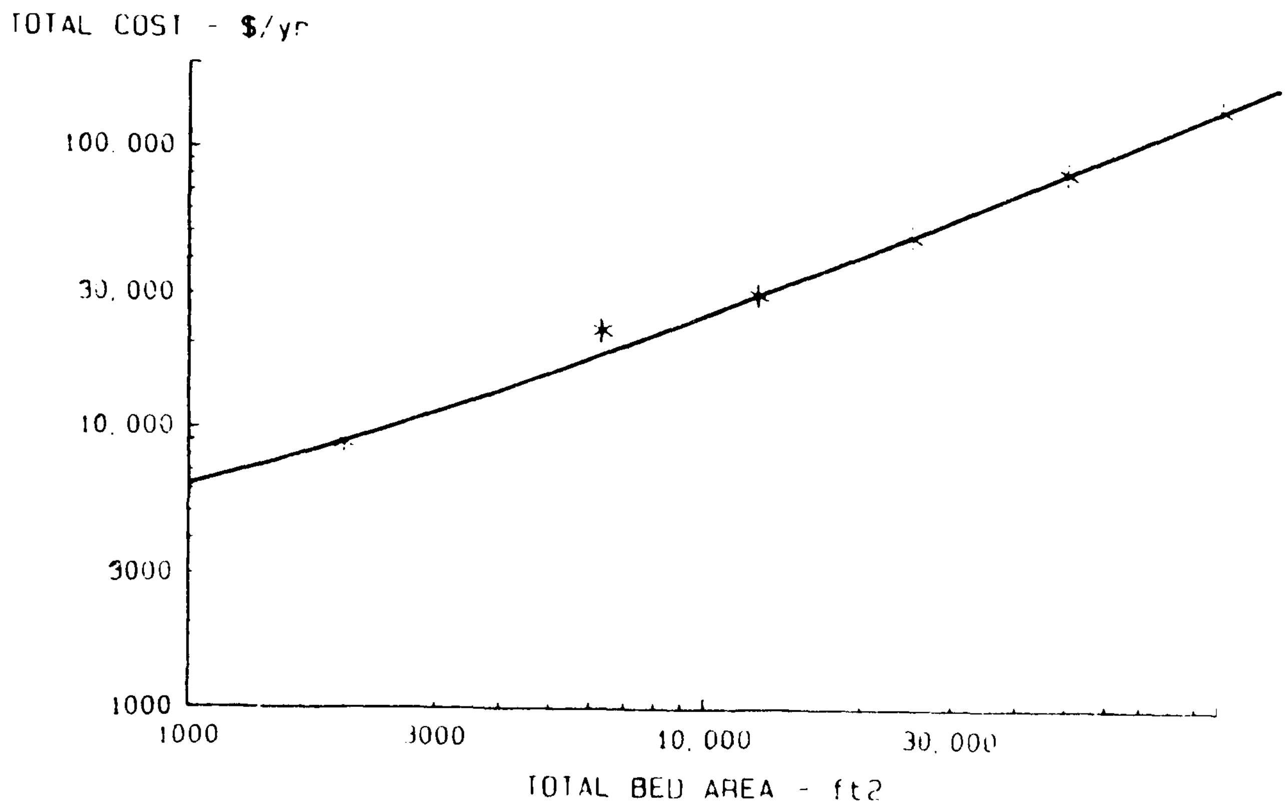

Figure 21. **Operation and maintenance costs for sand drying beds.** (Source: D. A. Cornwell et al., *Water Treatment Plant Waste Management* [AWWA Research Foundation, June 1987]. Used with permission.)

Tests conducted in New York State indicated that a 0.3 percent solids sludge placed in a lagoon in January with a depth of 30 in. and subjected to natural freezing had dewatered to 35 percent solids as of the next August by liquid decanting.[91] Allowing the sludge to stand for 1 week in 80 °F weather then increased the solids content to about 50 percent, suitable for handling and disposal in a landfill.

At the Akron, NY water treatment plant (1.5 mgd capacity), the sedimentation basins are cleaned in the spring and fall and the sludge is pumped to a thickener where it is removed every 3 or 4 weeks to three drying beds. The overall dimensions of the combined beds are approximately 50 ft by 30 ft. The sludge is applied no more than 1 ft thick, which dries to about 4 in. of solids. Sludge is removed from the drying beds during the summer and fall as it dries. Some sludge discharged in the fall is frozen and exhibits very good dewatering and handling characteristics--like a fine sand.[92]

Mechanical Dewatering

Various mechanical dewatering systems have been tested on all types of water treatment plant sludge. Centrifugation, belt press filtration, vacuum filtration, and pressure filtration are the most widely accepted methods.

Centrifugation

Centrifugation is basically a settling process compressed into a shallow depth. It uses centrifugal force created by rotating a liquid at high speeds to increase the settling rate of solids. Among the different types of applicable commercial centrifuges are the scroll-discharge, the solid-bowl decanter, the plow-discharge, and the basket-bowl. The most commonly used centrifuge for dewatering of water treatment sludges is the continuously discharging solid-bowl decanter centrifuge.

The solid-bowl centrifuge is a horizontal unit that has a scroll conveyor inside the centrifuge bowl, as shown in Figure 22.[93] The unit is fed continuously, with the solids settling against the bowl wall. The scroll rotates at a slightly different speed than the bowl and conveys the dewatered sludge to the small end of the centrifuge where it is discharged. The water moves from the central axis of the centrifuge toward the large end where it is discharged.[94]

The best procedure for evaluating centrifuges is to pilot test prototype equipment. Tests should be conducted on a centrifuge exactly like that to be used in full-scale except smaller. Operational parameters to test include feed flow rate, polymer conditioning, feed SS concentration, bowl speed, pool depth, and scroll speed. The best indicators of performance are cake solids concentration and centrate SS concentration. A pilot machine with a variable speed motor should be used so that machine variables such as bowl speed and pool depth can be evaluated as well as sludge characteristics. Methods for scaling up to production units can be found in *Water Treatment Plant Waste Management.*

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[91] G. P. Fulton, "Disposal of Wastewater From Water Treatment Plants," *JAWWA*, Vol 61 (July 1969).

[92] D. A. Cornwell et al. (June 1987).

[93] R. B. Williams and G. L. Culp.

[94] D. A. Cornwell et al. (June 1987).

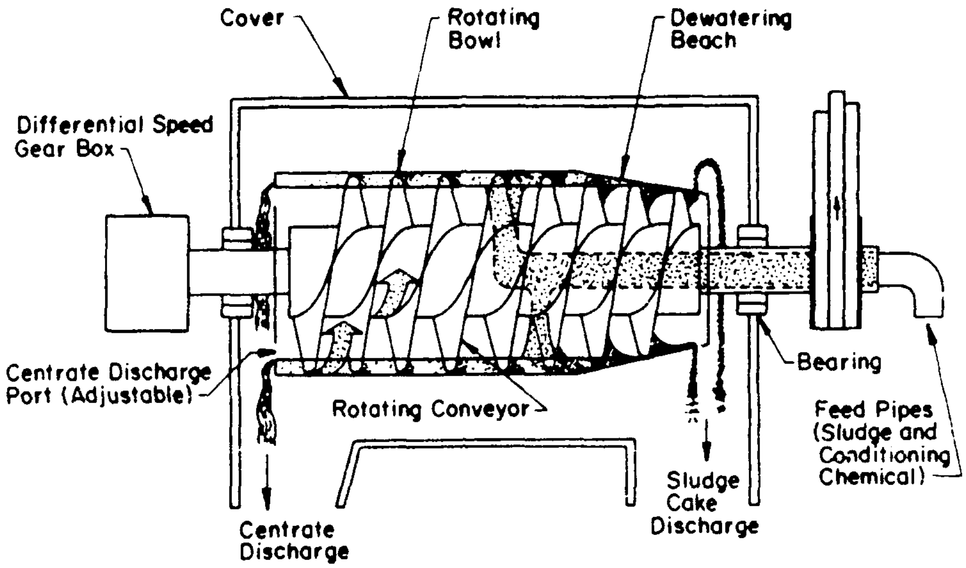

Figure 22. Continuous countercurrent solid-bowl centrifuge. (Source: *Handbook of Public Water Systems.*

An advantage to the centrifuge compared with other dewatering methods is the small space requirement. The centrifuge can also handle higher-than-design loadings, such as temporary increases in hydraulic loadings or solids concentration. The percentage solids recovery can usually be maintained with the addition of more polymer; although the cake solids concentration will drop slightly, the centrifuge will remain online.[95]

It is better to operate the centrifuge at a low bowl speed. The best performance data have been obtained at about 75 to 85 percent of the total solids or hydraulic capacity of the centrifuge.[96] At slightly below maximum capacity, the lowest polymer consumption is observed and the driest cake is obtained.

Overall raw water characteristics affect the dewatering property of coagulant sludge. Alum sludges containing high raw water turbidity, clay additives, or lime may produce higher cake solids concentrations with lower polymer requirements than pure alum sludges. The Erie County, NY, Sturgeon Point plant reported a 24 to 28 percent cake solids content with about 98 percent solids recovery using 3 lb polymer/ton of solids.[97] A plant in El Sobrante, CA treats a good quality water with turbidities normally 2 to 10 NTU. The solid-bowl centrifuge produces a 16 to 18 percent dry solids cake with a dry polymer feed rate of 3 to 6 lb/ton.[98]

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[95]R. B. Williams and G. L. Culp.

[96]AWWA Committee on Sludge Disposal, "Water Treatment Plant Sludges - An Update of the State of the Art, Part 2," *JAWWA* (October 1978).

[97]R. B. Williams and G. L. Culp.

[98]H. L. Nielson, "Alum Sludge Disposal--Problems and Success," *JAWWA*, Vol 69 (June 1977).

Softening sludges are dewatered more easily than coagulation sludges. Lime-softening sludges can be thickened to 55 to 70 percent solids with a 91 to 96 percent solids recovery and 1.0 to 1.5 percent solids in the centrate.[99] If the Ca:Mg ratio is high (above 5), the solids content of the cake will be about one-third higher than if this ratio is low (close to 1).[100]

Figures 23 and 24 are cost curves for solid-bowl decanter centrifuges. The capital cost curve appears in Figure 23. Capital costs cover manufactured equipment, pipes, valves, electrical work, instrumentation, and housing. Equipment costs include the base centrifuge machine, drive motor, hydraulic backdrive, one centrate storage hopper, dual centrate pumps, and flex connectors. Sludge feed and filtrate pumps are not included, nor is the sludge conditioning cost. Two-story housing is provided.[101]

Figure 24 shows the O&M cost curve. For centrifuges, these costs include process energy, maintenance material, and labor costs. Maintenance material costs represent replacement parts, resurfacing of the scrolls, and general maintenance.[102]

Pressure Filtration

Pressure filtration is the separation of water from a liquid sludge slurry using a positive pressure differential as the driving force. The two filter presses commonly used are the fixed volume recessed plate type and the diaphragm type. The fixed-volume pressure filter contains a series of filter plates held in a frame, as shown in Figure 25. The plates are pushed tightly together, by hydraulic or electromechanical means, to make the compartment leak-proof. Liquid sludge is pumped by high-pressure pumps into a volume between two filter plates, each of which has a filter cloth on it. As a result of high pressure on the sludge, a large portion of the water in the feed sludge passes through the filter cloth and drains from the press. When continued pumping is no longer productive, pumping is stopped and the press is opened to release the dewatered sludge cake before a new "pressing cycle" begins. Figure 26 shows a typical filter press installation.

In a diaphragm filter press, sludge is pumped into the press at a low pressure until the press has been filled with a loosely compacted cake; then sludge pumping is stopped and the diaphragm is inflated for a preset time. Although most of the water is removed when sludge is being pumped into the press, a significant amount is also removed after the diaphragm is inflated. After the preset time has elapsed, the diaphragm is deflated and the press opens, allowing the cake to drop out the bottom. The filter cloth is washed periodically by permanent spray nozzles. Figure 27 shows the basic configuration of one cell of a diaphragm press and the four separate stages of operation.[103]

Although the diaphragm press is a relatively new innovation, it is becoming increasingly popular because it has several advantages over the fixed-volume filter press. First,

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[99] A. J. Kramer and J. Whitaker, "Sludge Handling," *Water and Wastewater Engineering* (May 1975).
[100] AWWA Sludge Treatment and Disposal Committee Report.
[101] D. A. Cornwell et al. (June 1987).
[102] D. A. Cornwell et al. (June 1987).
[103] R. B. Williams and G. L. Culp.

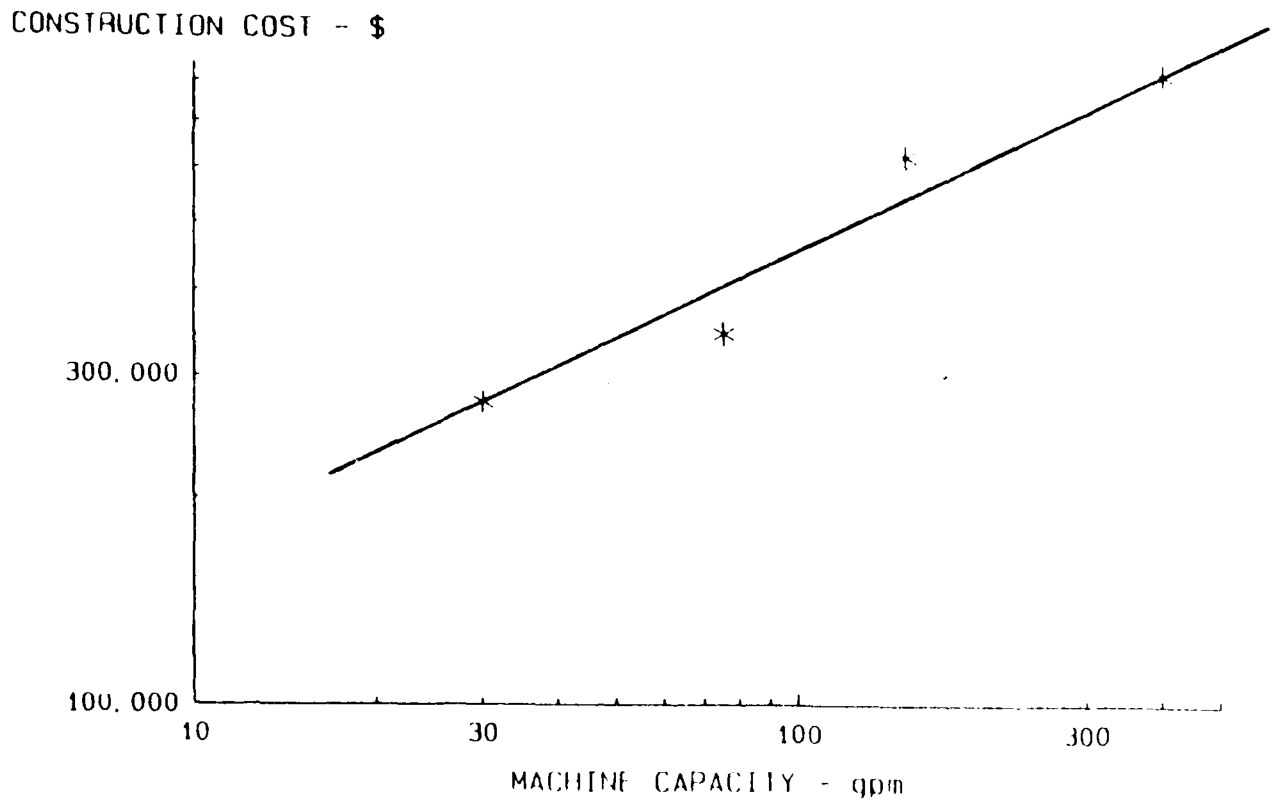

Figure 23. Construction cost for decanter centrifuges. (Source: D. A. Cornwell et al., *Water Treatment Plant Waste Management* [AWWA Research Foundation, June 1987]. Used with permission.)

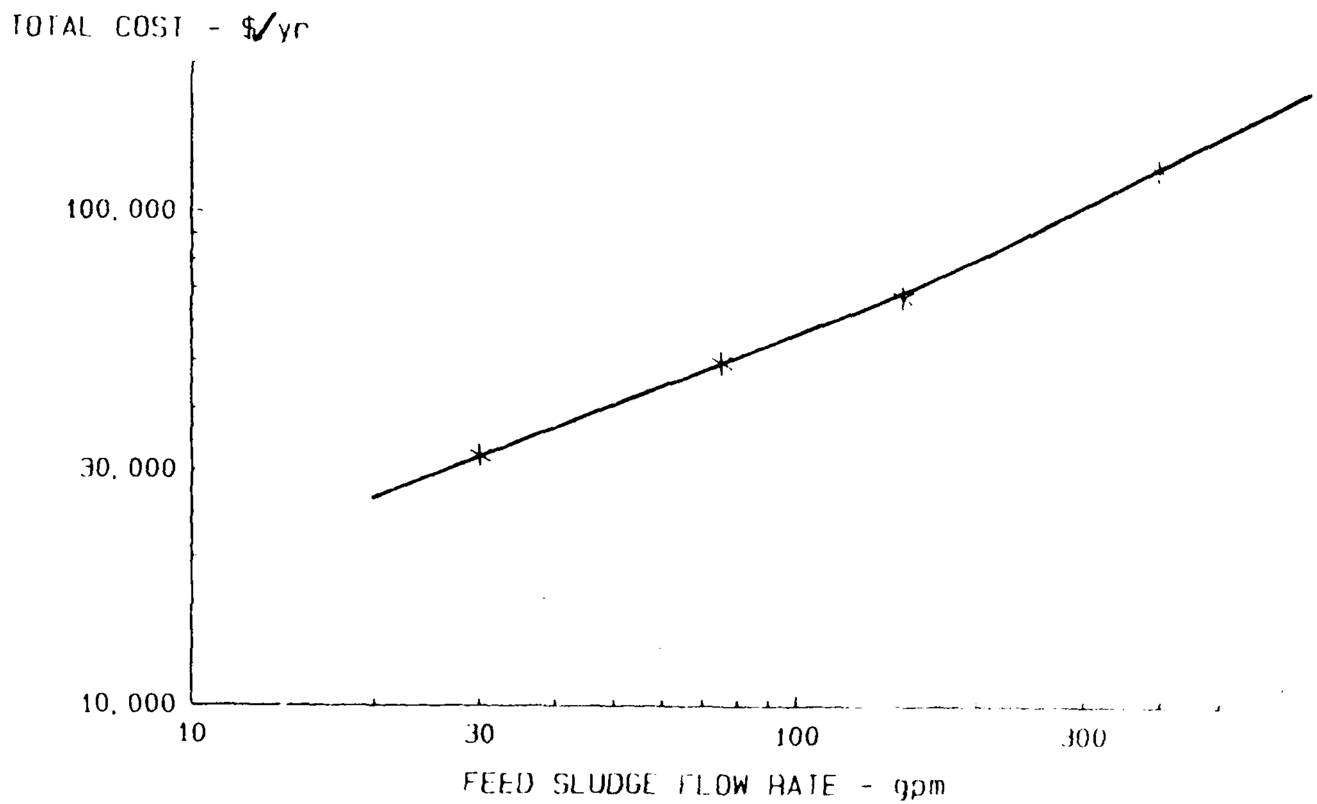

Figure 24. **Operation and maintenance costs for decanter centrifuges.** (Source: D. A. Cornwell et al., *Water Treatment Plant Waste Management* [AWWA Research Foundation, June 1987]. Used with permission.)

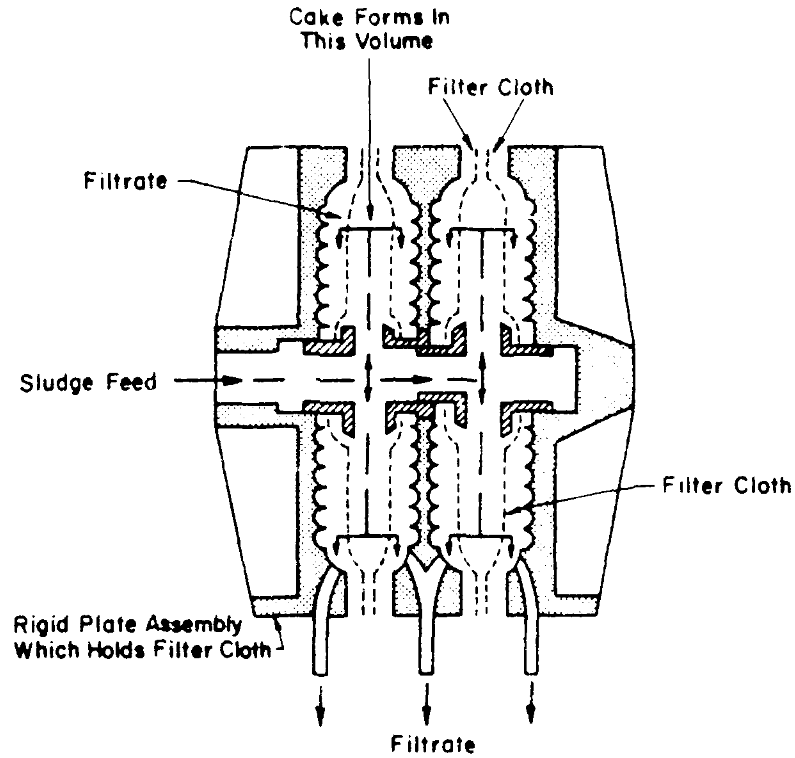

Figure 25. Cross section of a fixed-volume recessed plate filter press assembly. (Source: R. B. Williams and G. L. Culp [Eds.], *Handbook of Public Water Supply* [Van Nostrand Reinhold, 1986]. Used with permission.)

a drier cake with a relatively uniform moisture content is produced. In contrast, the inner part of the cake produced in the fixed-volume press is generally of low solids content. The second advantage is an overall shorter cycle time and therefore a higher production throughput. The diaphragm press also has lower O&M requirements for the sludge feed pumps and can dewater a marginally conditioned sludge to a high solids content.[104] Generally, the fixed-volume press cannot dewater a marginally conditioned sludge to a satisfactory cake concentration. Another advantage is that the diaphragm press does not require a precoat, whereas precoating is frequently necessary with a fixed-volume press. However, the diaphragm has an initial cost two to three times that of a fixed volume press. Also, the capacity of the largest diaphragm filter is generally less than that of the largest fixed-volume plate filter press.

Filter presses are normally installed well above floor level so that the cakes can drop into trailers positioned underneath the presses or onto conveyors that transport them to a storage area.

For pressure filtration to be economical, alum sludges must be conditioned to lower their resistance to filtration. Lime or fly-ash can be used for conditioning. If lime is used, it is added until the pH of the sludge reaches 11, and a reaction time of 30 min should be allowed before filtering. Lime can be added in two stages, with an interim period in between when sludge settles, after which the clear water can be poured off. This method can result in less lime required overall.[105]

[104] R. B. Williams and G. L. Culp.

[105] AWWA Committee on Sludge Disposal.

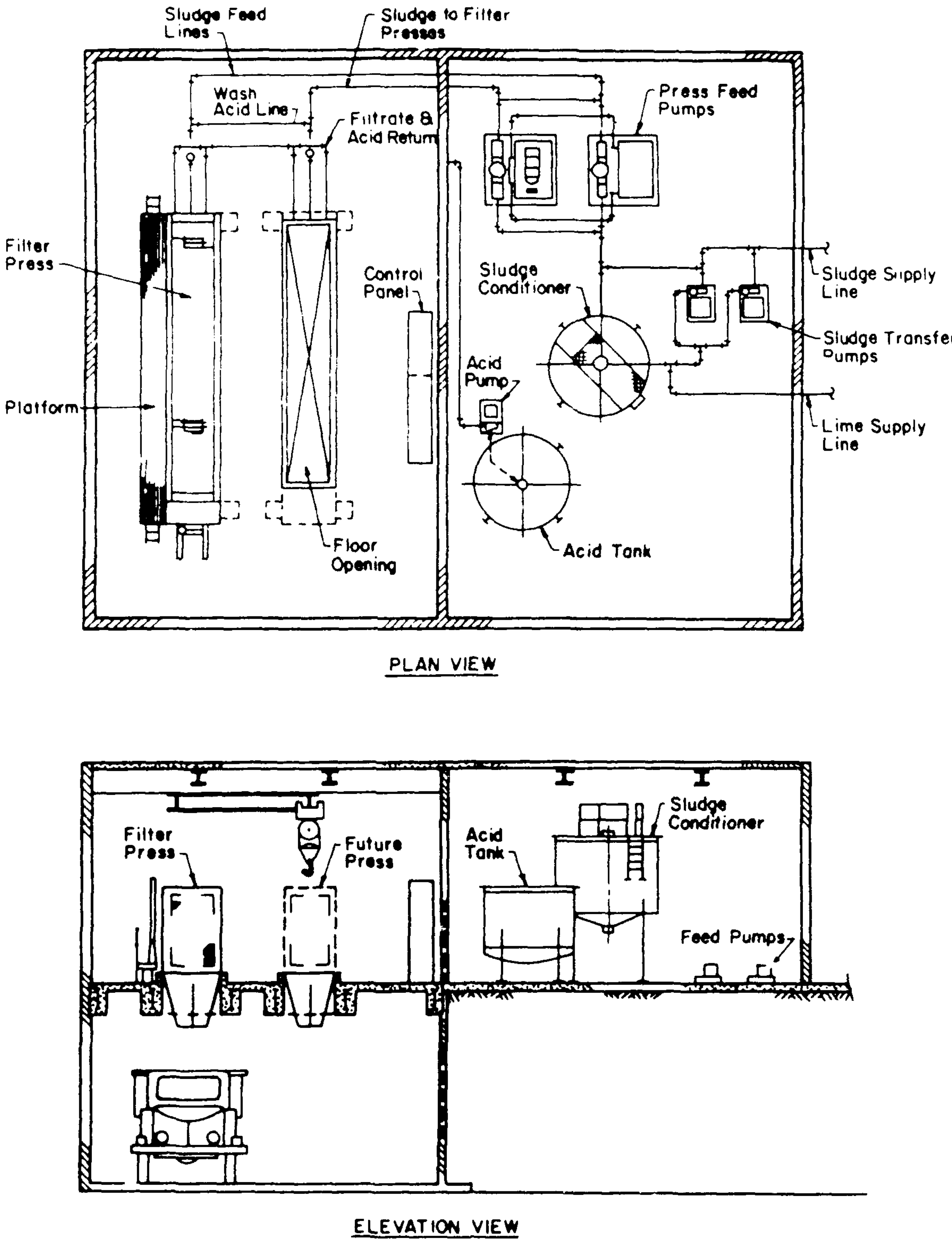

Figure 26. **Typical filter press installation.** (Source: R. B. Williams and G. L. Culp [Eds.], *Handbook of Public Water Supply* [Van Nostrand Reinhold, 1986]. Used with permission.)

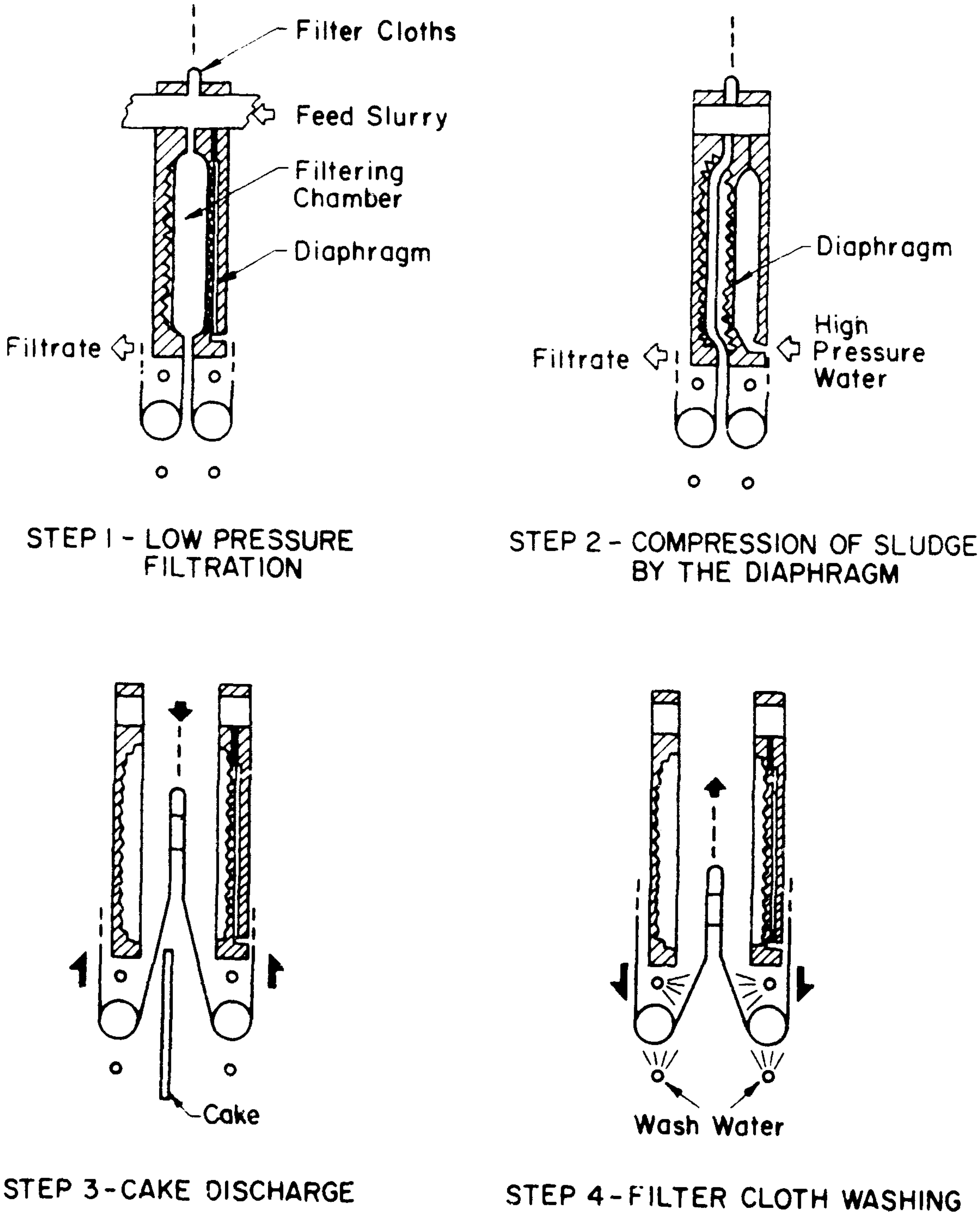

Figure 27. Operational cycle for a Lasta diaphragm filter press. (Source: R. B. Williams and G. L. Culp [Eds.], *Handbook of Public Water Supply* [Van Nostrand Reinhold, 1986]. Used with permission.)

Disposal of filtrate produced during pressure filtration is a problem because of the chemical properties of the material. The conditioned sludge has a pH of about 11.5, which causes part of insoluble aluminum hydroxide to be converted to soluble aluminate. Also, precoat material can contribute potentially significant concentrations of trace metals to the filtrate. Special treatment may be required before recirculating filtrate to the head of the plant or discharging it.

The major advantage of the pressure filter press when compared to the other mechanical dewatering equipment is the high solids concentration in the formed cake and the high clarity of the filtrate. Thus, filter presses have become increasingly attractive when cake disposal is a critical factor.[106] Filter press testing at several New York water treatment plants was conducted on alum sludges. Filter cake concentrations of 40 to 50 percent solids were obtained in laboratory experiments and in a trailer-mounted pilot plant. Filtrate quality was suitable for inclusion as raw water, lime requirements were 25 percent of the waste solids on a dry weight basis, and the precoat was approximately 2 percent of the waste solids. The cycle time ranged from 90 to 120 min.[107] An AWWA committee on sludge disposal reported that alum sludge is usually gravity-thickened to about 2 to 6 percent solids (by weight) and then dewatered mechanically to 40 to 50 percent solids.[108]

Probably the most controllable factor that affects the rate of filtration after a particular pressure filter press is in operation is the conditioning of the sludge. The tests on specific resistance, CST, and high-pressure filtration can be used to measure the effectiveness of the conditioner used.[109]

Cost curves for the diaphragm filter press are presented since this type of filter press is becoming the most popular. Figure 28 shows the construction cost curve. Construction costs cover equipment, labor, piping and valves, electrical work, instrumentation, and two-story housing. The equipment cost is divided into filter press equipment, washer-shaker mechanism, and ancillary equipment. The ancillary equipment includes feed pumps, sludge holding tank, filtrate control valve, air compressor system, one centrifugal pump for initial fill of the press, and one progressive cavity pump for pressurized pumping. Polymer and/or lime conditioning costs are not included. The O&M cost curve is shown in Figure 29. These costs include process energy, maintenance materials, and labor costs. Process energy is mostly for the feed pumps, but also includes the plate shifting mechanism and ancillary equipment operation.[110] The filter press is not usually used for dewatering softening sludges.

Belt Press Filtration

Belt filter presses use single or double moving belts to continuously dewater sludges. All belt filter presses include three basic operational stages: chemical conditioning, gravity drainage, and shear and compression dewatering of the drained sludge. Figure 30 shows a simple belt press and the location of the three stages.[111] Two endless belts of synthetic fiber pass around a system of rollers at constant speed. The

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[106] D. A. Cornwell et al. (June 1987).

[107] R. M. Gruninger, "Disposal of Waste Alum Sludge From Water Treatment Plants," *Journal of the Water Pollution Control Federation*, Vol 74, No. 3 (1975).

[108] AWWA Committee on Sludge Disposal.

[109] D. A. Cornwell et al. (June 1987).

[110] D. A. Cornwell et al. (June 1987).

[111] R. B. Williams and G. L. Culp.

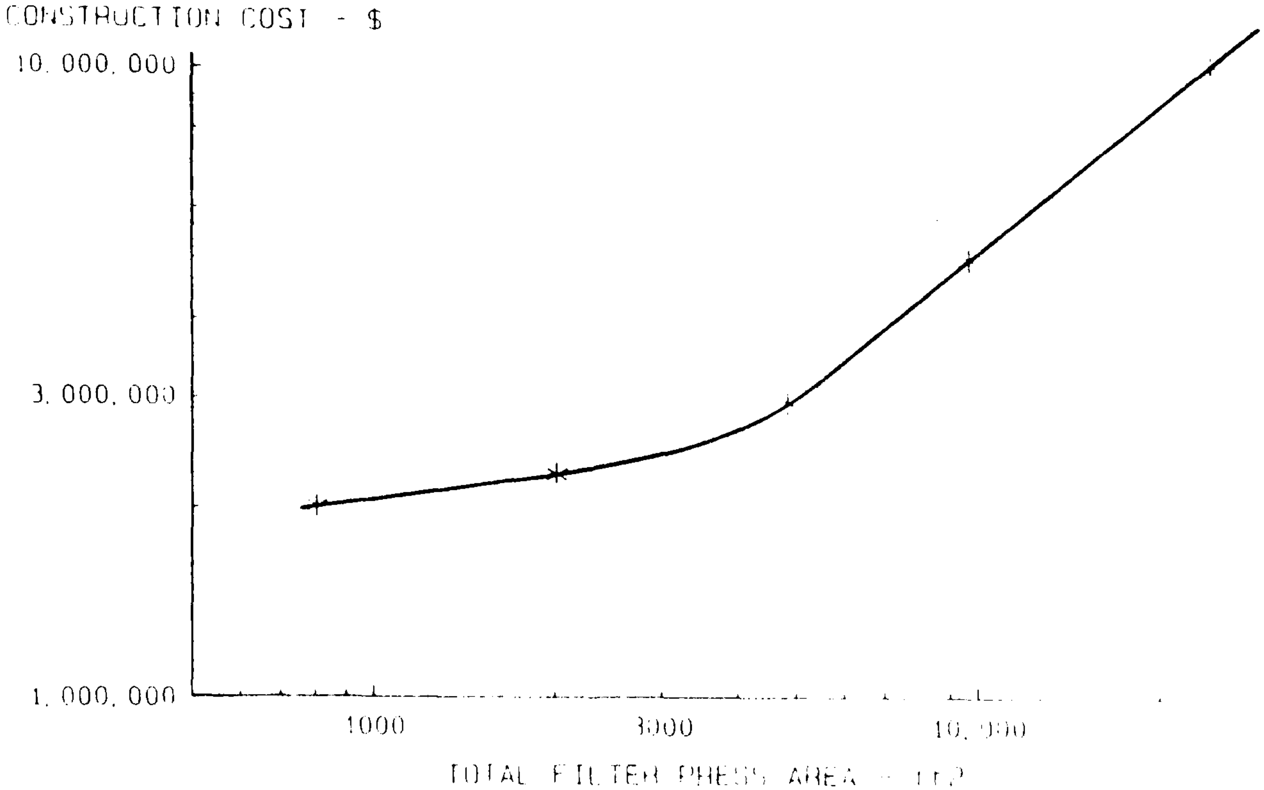

Figure 28. **Construction cost for diaphragm filter press.** (Source: D. A. Cornwell et al., *Water Treatment Plant Waste Management* [AWWA Research Foundation, June 1987]. Used with permission.)

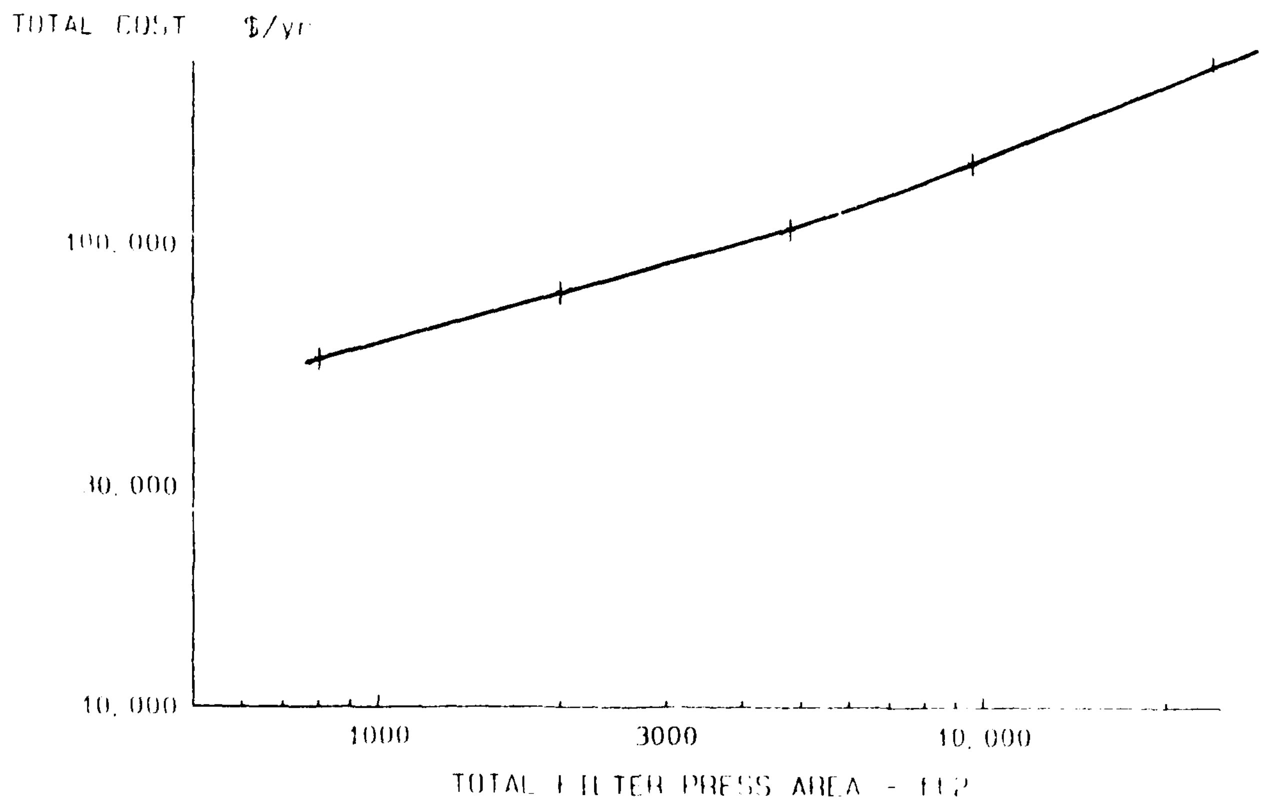

Figure 29. Operation and maintenance costs for diaphragm filter press. (Source: D. A. Cornwell et al., *Water Treatment Plant Waste Management* [AWWA Research Foundation, June 1987]. Used with permission.)

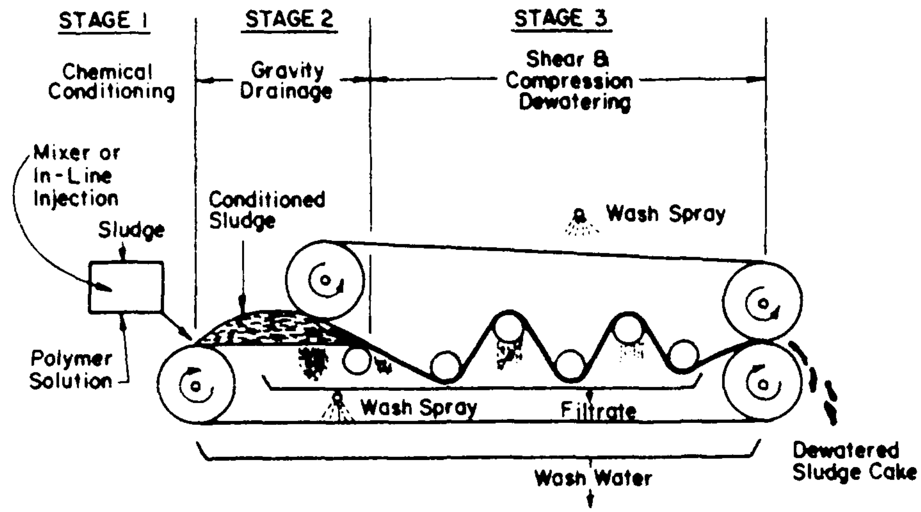

Figure 30. **The three basic stages of a belt filter press.** (Source: R. B. Williams and G. L. Culp [Eds.], *Handbook of Public Water Supply* [Van Nostrand Reinhold, 1986]. Used with permission.)

dewatering process begins after the feed sludge has been conditioned, usually with polymer. The slurry enters the gravity drainage stage, where it is distributed evenly onto a moving porous belt. Following gravity drainage, the partially dewatered sludge enters the compression dewatering stage. Here the sludge is "sandwiched" between two porous cloth media belts that travel in an S-shaped path over numerous rollers. Both belts operate under a specific tension that induces dewatering pressure onto the sludge. The S-shaped path the sludge follows creates shear forces to assist in the dewatering process. The compressive and shear forces working on the sludge increase over the length of this dewatering stage. The final sludge cake is removed from the belts by blades. Two spray-wash belt cleaning stations are generally used to wash the belt after cake discharge and before the next dewatering cycle.

Belt press performance is measured by the percentage solids in the sludge cake, the solids and hydraulic loading rates, and the required polymer dose. Machine variables such as belt speed, belt tension, and belt type influence belt press performance.[112]

The belt speed determines the retention time of the sludge in the press and therefore the amount of time the sludge is subjected to pressure. Low belt speeds result in drier sludge cakes. Hydraulic capacity increases at higher belt speeds, but the solids capture drops. Depending on the desired performance, the belt speed setting can be used to produce a variety of results.

Belt tension has an effect on cake solids, maximum solids loading, and solids capture. In general, a higher belt tension produces a drier cake but causes a lower solids capture and increased belt wear. For predominantly alum sludges, the belt tension must be reduced to contain the sludge between the belts. The maximum tension that will not cause sludge losses from the sides of the belts should be used.[113]

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[112] R. B. Williams and G. L. Culp.
[113] R. B. Williams and G. L. Culp.

Belt type is an important factor in determining overall performance. Most belts are woven of polyester filaments and are available in weaves of varying coarseness and strength. A belt with one of the coarser, stronger weaves may require high polymer doses to obtain adequate solids capture.

Failure of the chemical conditioning process to adjust to changing sludge characteristics can cause operational problems. If sludge is underconditioned, improper drainage occurs in the gravity drainage section, and either sludge will be lost out the sides from the compression section or uncontrolled overflow from the drainage section may occur. Both underconditioned and overconditioned sludges can blind the filter media. In addition, overconditioned sludge drains so rapidly that solids cannot be distributed across the belt. Most manufacturers' belt presses can be equipped with sensing devices that can be set to automatically shut off the sludge feed flow in case of underconditioning.[114]

Belt filter presses can produce a filter cake with 12 to 20 percent solids by weight for alum sludge.[115] Dewatering combined alum/lime sludges at the Gastonia, NC water treatment plant produces a cake solids concentration of 25 percent using 3 to 8 lb polymer/ton of dry solids. Typical performance data of belt filter presses on lime softening sludge at three water plants have been summarized by Hambor.[116] Feed sludge concentrations are about 20 to 25 percent solids, and cake solids concentrations are 60 to 70 percent. The solids recoveries are 90 to 95 percent and polymer requirements are typically 2 to 3 lb/ton of dry solids.

Figure 31 shows capital cost curves for the belt filter press. The construction costs cover the belt filter press equipment, installation labor, piping and valves, electrical work, instrumentation, and two-story housing. The belt filter press equipment cost includes that of the belt filter press and the hydraulic power unit. Not covered in the equipment cost is the sludge feed pump and the polymer conditioning system. The filtrate normally flows by gravity from the belt filter press; therefore, a filtrate pump is not provided.[117]

The O&M costs are shown in Figure 32. These costs cover process energy, maintenance material, and labor. Process energy costs were developed using total connected horsepower. O&M costs for belt filter presses are very dependent on the sludge characteristics and may vary widely among sludges.[118]

Vacuum Filtration

A drum with a filter cloth stretched over it rotates through the sludge in this method (Figure 33). A pressure differential across the sludge causes the sludge to thicken on the outside of the drum and filtrate to pass to the inside. The angular speed of the drum is usually 0.2 to 0.5 rpm with a vacuum of 15 to 25 in. Hg.[119]

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[114] R. B. Williams and G. L. Culp.

[115] *The Quest for Pure Water*, Vol II (AWWA, 1981).

[116] J. M. Hambor, "Dewatering of Water Treatment Sludges--The Belt Filter Press," paper presented at the AIChE Joint Meeting--Central and Peninsular Sections, Clearwater Beach, FL (May 1983).

[117] D. A. Cornwell et al. (June 1987).

[118] D. A. Cornwell et al. (June 1987).

[119] AWWA Sludge Treatment and Disposal Committee Report.

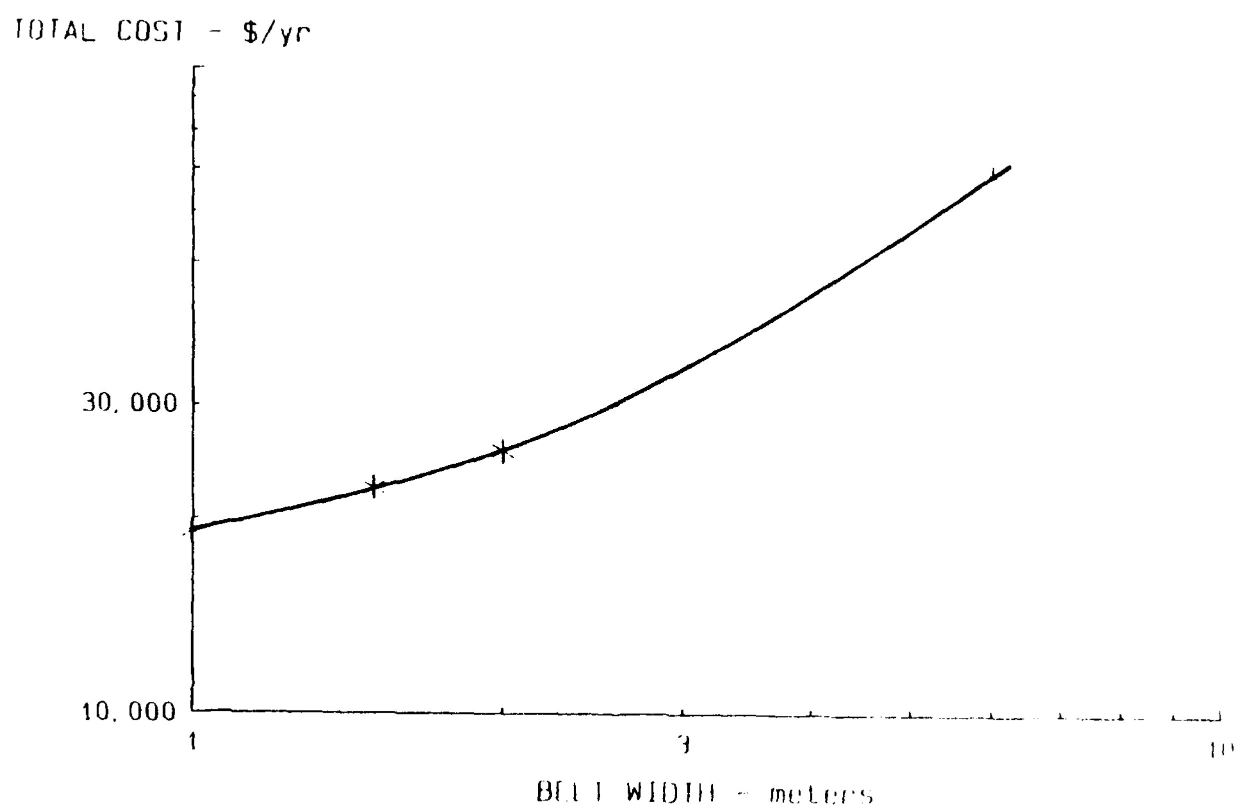

Figure 31. Operation and maintenance costs for belt filter press. (Source: D. A. Cornwell et al., *Water Treatment Plant Waste Management* [AWWA Research Foundation, June 1987]. Used with permission.)

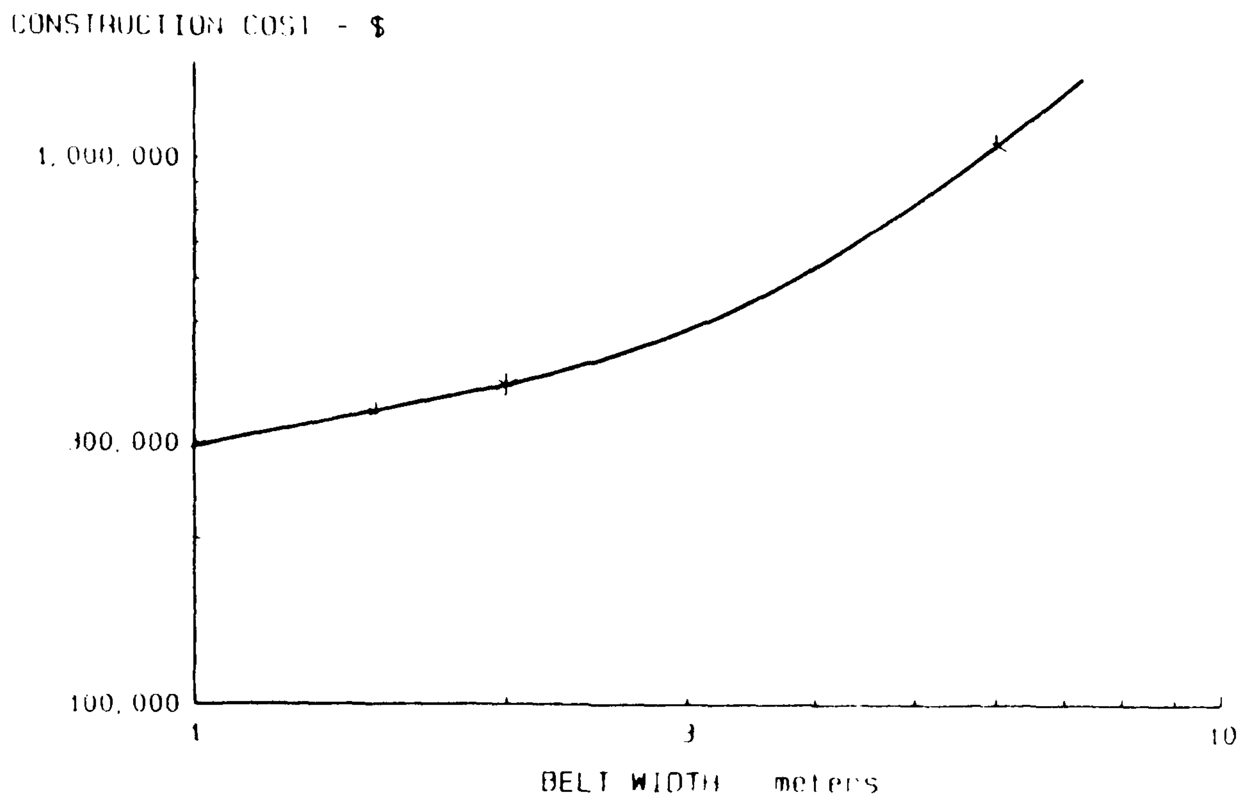

Figure 32. Construction cost for the belt filter press. (Source: D. A. Cornwell et al., *Water Treatment Plant Waste Management* [AWWA Research Foundation, June 1987]. Used with permission.)

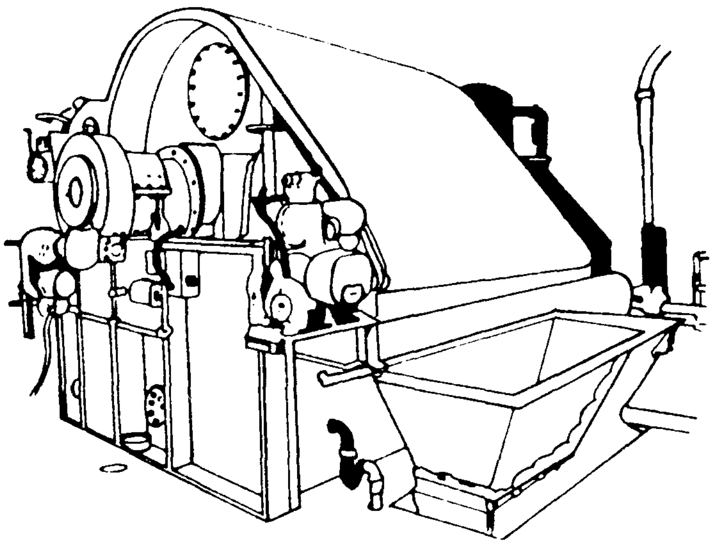

Figure 33. Vacuum filter. (Reprinted with permission from *Water Supply and Sewerage*, 1979, E. W. Steel, T. J. McGhee, courtesy of Envirex, Inc., a Rexnord Company.)

Filter medium selection is important to avoid blinding of the medium. An example is polypropylene monofilament belt medium, rated at an airflow of 300 cfm/sq ft at 15 in. Hg with a loading of 1.4 lb/sq ft-hr.[120]

There are two types of vacuum filters. The traveling medium type has a moving belt that continually removes the medium from the drum and washes it with a high-pressure spray. The precoat medium filter has the precoating shaved off in small increments (0.005 in.) while the drum slowly rotates.[121] Precoat medium filters are usually used with coagulation sludges. Traveling medium filters commonly require a filtration aid such as polymer, lime, or both.

This method works better on lime-softening sludge or combined softening-coagulation sludges than coagulation sludges.[122] A filter cake with a 40 to 70 percent SS content can be produced from lime-softening sludge. Filter loadings range up to 90 lb/sq ft-hr with a feed solids concentration of 5 to 30 percent and a filtrate solids concentration of 0.1 to 0.15 percent.[123] The solids content of long-term settled sludge can indicate the cake solids content achievable by vacuum filtration. The two primary factors affecting performance are the solids feed concentration and the magnesium hydroxide content.

Based on plant operating experience, the solids content of the filter cake is much higher if the plants have sludge with a Ca:Mg ratio above 5, compared to plants with a

[120]AWWA Committee on Sludge Disposal.
[121]AWWA Committee on Sludge Disposal.
[122]R. J. Calkins and J. T. Novak.
[123]AWWA Sludge Treatment and Disposal Committee Report.

ratio below 1.[124] The magnesium content does not affect how easily the sludge is filtered; it does, however, affect the solids content achievable in the filter cake.[125]

Alum sludges can achieve cake solids concentrations of 15 to 17 percent when a polymer conditioner is used. About 30 to 40 percent is possible if a lime conditioner is used.

Filter backwash generally does not filter well because it usually contains few softening residues and has a low solids content. Filterability is measured in terms of the specific resistance. In general, sludges with a specific resistance below 2.835×10^9 sec^2/oz filter well and those with a specific resistance above 1.418 sec^2/oz filter poorly.[126]

Figure 34 shows construction costs for vacuum filters. These costs cover the vacuum filter equipment, labor, pipes and valves, electrical work, instrumentation, and two-story housing. The vacuum filter equipment cost includes the vacuum filter, vacuum pump, vacuum receiver, and filtrate pump. Not included is the cost of the sludge feed pump, sludge conditioning, and additional sludge cake handling costs. For precoating, the lime-conditioning system costs can be added to the vacuum filter construction and O&M costs. Operating and maintenance costs are shown in Figure 35.[127]

Treating the Supernatant

In many instances, the supernatant from treatment of solids is good enough quality to be recycled to the head of the plant. This recycling is actually the "zero discharge" goal of the Water Pollution Control Act Amendments of 1972.[128] If sludge treatment contributes other contaminants (as in the case of pressure filtration where fly-ash is used to precoat the filter, or where lime conditioning raises the pH and causes metals to go into solution), further treatment of the supernatant may be required before recycling or discharging. Local authorities would have jurisdiction on discharging this water to sewers.

In many cases, recycling the supernatant with a low SS content can enhance coagulation by either reducing the alum requirements or acting as a seed for precipitation of coagulant products.[129]

Sludge Pelletization

Sludge pelletization involves a different type of lime-softening process: suspended bed cold softening. It produces a smaller amount of more easily dewatered sludge. This process is well suited to warm groundwater with a high calcium content, typically found in the southeastern United States.

[124] AWWA Sludge Treatment and Disposal Committee Report.
[125] R. J. Calkins and J. T. Novak.
[126] R. J. Calkins and J. T. Novak.
[127] D. A. Cornwell et al. (June 1987).
[128] L. E. Lang et al.
[129] L. E. Lang et al.

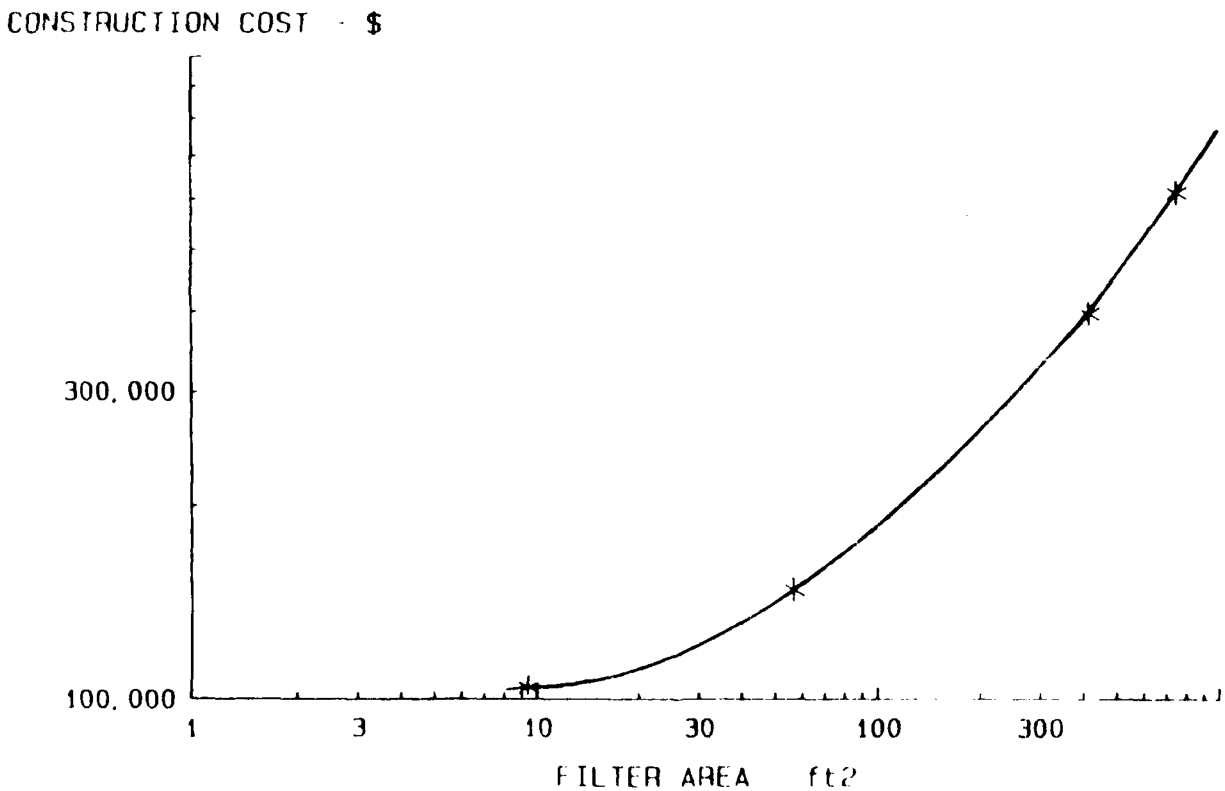

Figure 34. **Construction cost for vacuum filters.** (Source: D. A. Cornwell et al., *Water Treatment Plant Waste Management* [AWWA Research Foundation, June 1987]. Used with permission.)

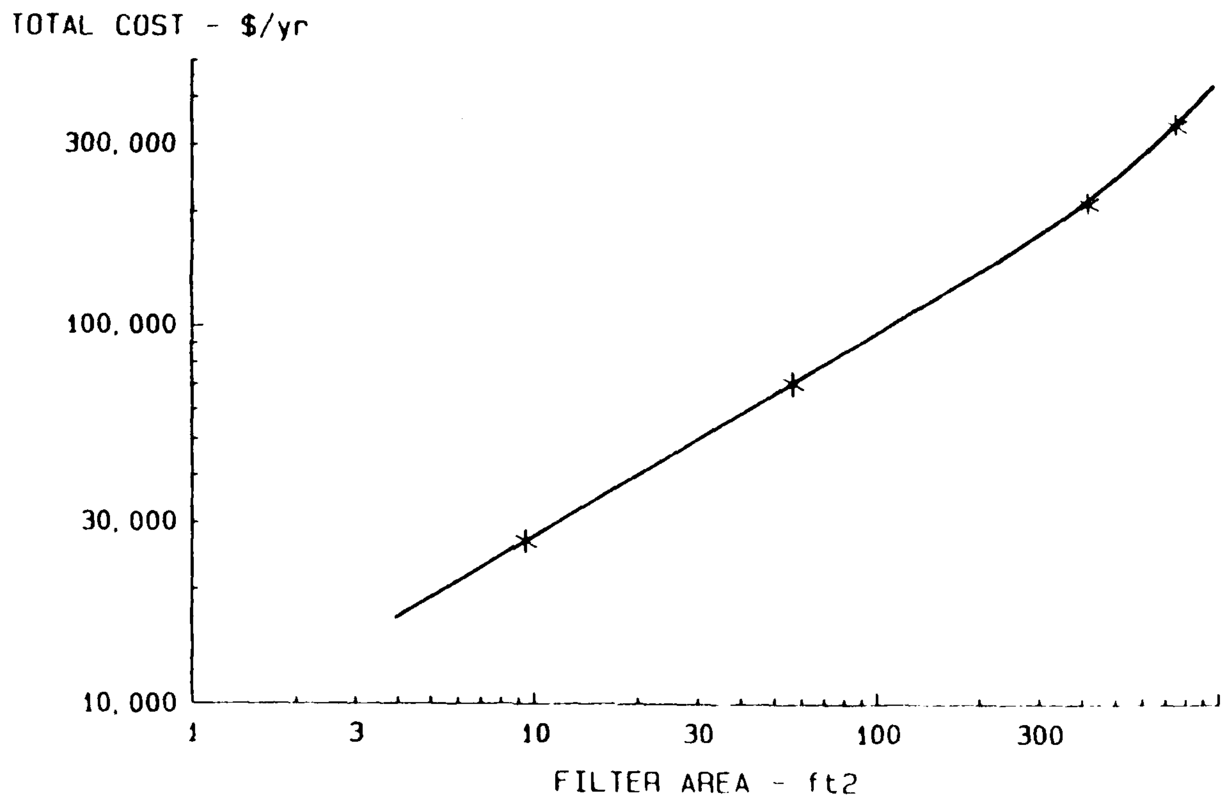

Figure 35. Operation and maintenance costs for vacuum filters. (Source: D. A. Cornwell et al., *Water Treatment Plant Waste Management* [AWWA Research Foundation, June 1987]. Used with permission.)

The reactor (Figure 36) is shaped like an inverted cone and is filled initially about two-thirds full with silica granules, 7.87×10^{-3} to 9.84×10^{-3} in. effective size, which act as a catalyst. The high-velocity, upward spiral flow of raw water suspends the granular catalyst, which is essential for efficient removal of hardness. Upward velocity is limited to about 3 ft/min at the top of the cone to prevent carryover of catalyst particles.[130]

Lime is injected into the reactor while the raw water flow is gradually increased from a low initial rate to design capacity. The lime reacts with calcium bicarbonate and carbon dioxide to form calcium carbonate, which precipitates on the suspended particles. It has been claimed that the size of the calcium-carbonate-coated particles can reach 6.3×10^{-2} in. diameter; however, operating experience has shown that maximum sizes are in the 2.8×10^{-2} to 3.9×10^{-2} in. range. Theoretically, reactors should be capable of continuous operation. However, this requires a fine balance between the blowdown of sludge pellets and the addition of new, granular catalyst to maintain a constant volume bed. This balance is difficult to achieve so, in practice, the reactors are usually operated in a batch mode.[131]

The catalyst granules will last 40 to 60 days before needing replacement. Finished water turbidity indicates when replacement is necessary. At the end of the run, the contents of the reactor, water, and sludge pellets are discharged into a storage and drainage facility. After drainage, the pellets can be treated as solids.

The sludge (spent silica granules) typically has a solids content of 60 percent by weight and will easily dewater to 90 percent. The pelletized sludge volume is 10 to 20 times smaller than the sludge from conventional softening treatment.[132]

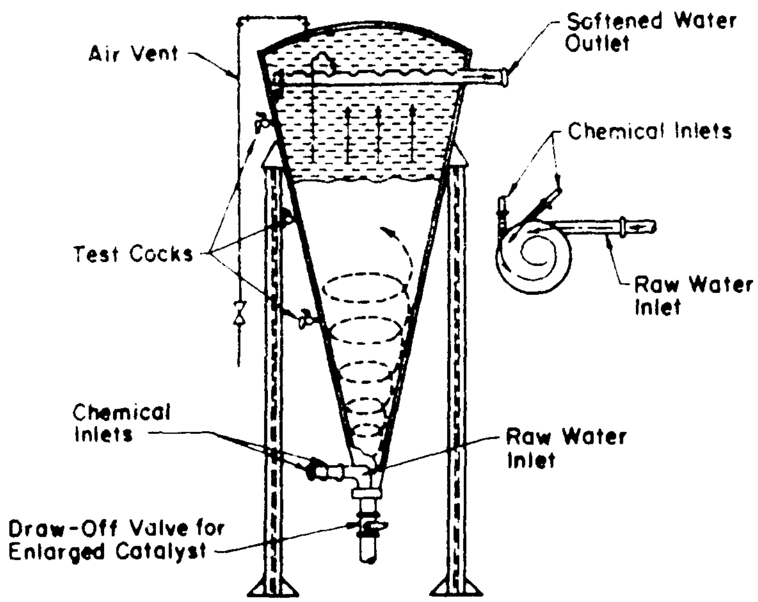

Figure 36. Reactor for lime sludge pelletization. (Courtesy of Permutit Co.).

[130] AWWA Sludge Treatment and Disposal Committee Report.
[131] R. B. Williams and G. L. Culp.
[132] AWWA Sludge Treatment and Disposal Committee Report.

The limitations on this approach are: magnesium content should be less than 85 mg/L as $CaCO_3$; turbidity should be less than 10; and, in cold climates, the reactors must be enclosed in heated structures. Excessive magnesium forms magnesium hydroxide, which does not plate out on the nuclei and will quickly clog downstream filters. Also, upflow rates are too high to permit removal of SS, which will also pass to downstream filters. This problem can be solved by adding the reactor ahead of a conventional clarifier.[133]

The pelletized sludge particles can be dumped in a landfill, but they may cause transportation problems due to their small, round size. Accidents could result from a spill occurring on a roadway.[134]

A suspended bed cold-softening reactor is in use at a U.S. Marine Corps installation.[135] The silica grains are obtained from the beach at no cost. For 1-mgd capacity, spent granules are replaced every 2 months and hauled by five dump trucks to sludge-drying beds at a local sewage treatment plant. In addition, every 2 weeks, one-half a dump truck load of granules is removed from the bottom of the reactor.

Chemical Recovery

The practice of recovering chemicals from water plant sludges has centered around the production of lime from lime-softening sludges and the reclaiming of alum or iron from coagulant sludges. The objective of chemical recovery is generally a combination of producing the recovered chemical at a cost less than the commercial price and reducing the amount of waste product requiring treatment or disposal. Processes for recovering chemicals from both types of sludges are being used; however, each has found only limited application. With the currently available technologies, it is probable that less use lime recovery will be used less in the future, with more use of coagulant recovery. However, more stringent disposal regulations could greatly increase the use of both lime and coagulant recovery.[136]

Alum Recovery

Recovery by Acidification. Aluminum recovery from sludges produced in water coagulation plants has been studied by many researchers since the early 1950s.[137] The traditional scheme for alum recovery consists of thickening sludge from settling basins and filter backwashings, reducing the pH by acid addition, and separating the dissolved aluminum (in the form of aluminum sulfate) by decanting it from the residual solids.[138] Figure 37 shows a potential layout for an alum recovery system with direct acidification of alum sludge. The solids requiring ultimate disposal are greatly reduced by alum recovery, and the remaining solids can be more easily dewatered for ultimate disposal.

A full-scale test of alum recovery showed that an annual average of 42 percent reduction in solids could be expected, along with a 64 to 79 percent recovery of alum.[139] These results would be expected to vary on a case-by-case basis.

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[133]R. B. Williams and G. L. Culp.

[134]R. B. Williams and G. L. Culp.

[135]L. E. Lang, et al.

[136]D. A. Cornwell et al. (June 1987).

[137]D. A. Cornwell and J. A. Susan, "Characteristics of Acid Treated Alum Sludges," *JAWWA*, Vol 71, No. 10 (October 1979).

[138]R. B. Williams and G. L. Culp.

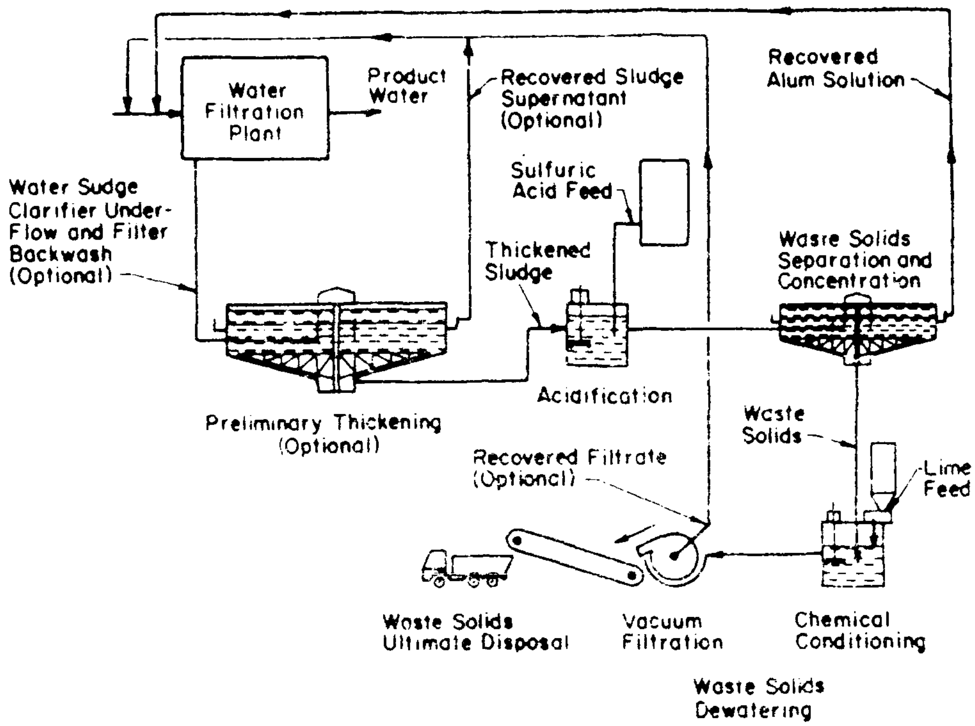

Figure 37. Acidic alum recovery flow diagram. (Source: R. B. Williams and G. L. Culp [Eds.], *Handbook of Public Water Supply* [Van Nostrand Reinhold, 1986]. Used with permission.)

The acidic alum recovery process presents potential problems. First, the recovered alum may contain impurities, such as certain metals, which may be present in the raw water and dissolve from the sludge. Also, the recovered alum is very dilute, presenting storage and operational problems.

Recovery by Liquid-Liquid Extraction. An alternative method of alum recovery has been investigated.[142] The goal was to preferentially remove aluminum from the sludge, thereby leaving any impurities with the solids. The objective was to also concentrate the recovered alum to a level near that of commercial liquid alum. The basic process as pilot-tested is shown in Figure 38.[141] Major components of the system are sludge collection and feed, extraction, stripping, and residual sludge treatment. A detailed description of the process can be found in *Water Treatment Plant Waste Management*. Results of approximately 500 hr of pilot-plant testing showed an aluminum recovery of 91 percent. The recovered alum was essentially of equal or better quality than commercial liquid alum. The system cost does not include that of treating residual sludge, which should be reduced in dry weight and exhibit improved drainability and dewatering characteristics. The residual sludge in the test showed a 50 percent reduction of dry weight solids and readily settled to a 10 percent solids concentration.[142] An overall economic analysis should compare the cost of treating the raw sludge with the cost of treating the residual sludge, plus or minus any costs of recovering the alum.

[140] D. A. Cornwell, "An Overview of Liquid Ion Exchange With Emphasis on Alum Recovery," *JAWWA*, Vol 71, No. 12 (1979).

[141] D. A. Cornwell and G. Cline, "Demonstration Testing of Alum Recovery by Liquid Ion Exchange," *JAWWA*, Vol 73, No. 6 (June 1981).

[142] D. A. Cornwell and G. Cline.

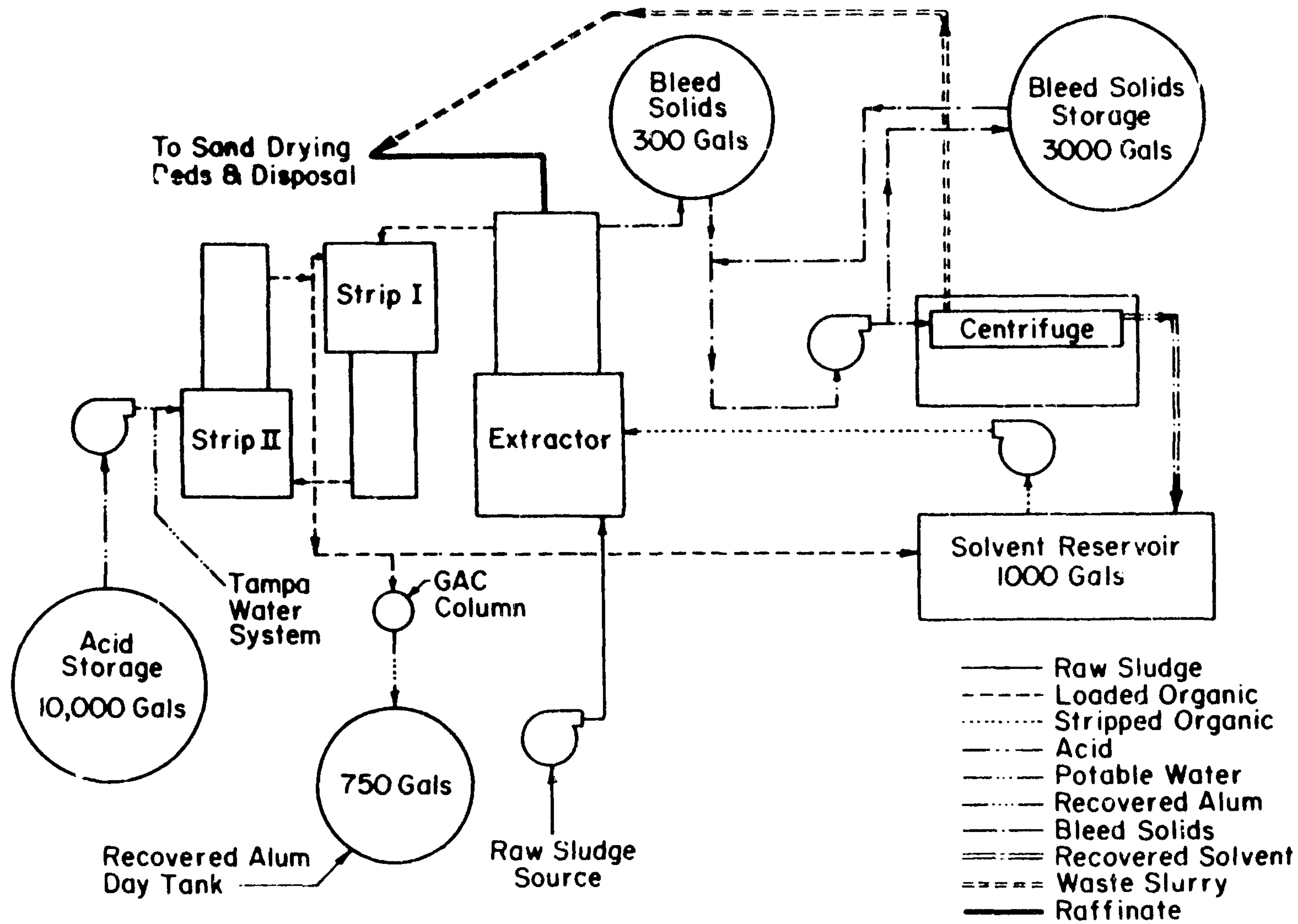

Figure 38. **Liquid-ion exchange alum recovery process.** (Source: D. A. Cornwell et al., *Water Treatment Plant Waste Management* [AWWA Research Foundation, June 1987]. Used with permission.)

Iron Coagulant Recovery

Recovery of iron coagulants involves acidification of ferric hydroxide and a recovery technique similar to that described for the acidic alum recovery process. The pH of the iron sludge is lowered by acid addition to a range where the solubility of ferric iron is significantly increased, and the iron is released back into solution. The pH must be reduced to 1.5 to 2.0 to attain 60 to 70 percent recovery of iron.[143]

The Athens Utilities Board in Athens, TN, operates the only iron recovery plant in the United States.[144] This plant treats about 6 mgd with a raw water turbidity of 18 NTU using a ferrifloc dose of 30 ppm. Backwash water is recycled to the head of the plant so that all solids are collected in the sedimentation basins. Sedimentation basin sludge at a solids concentration of 2 to 7 percent is pumped to a mixed reaction tank where sulfuric acid is added to reduce the pH to about 1.6. Polymer is added at a dose of 8 lb/ton of dry solids prior to dewatering on a vacuum drying bed. The acidification process results in a 50 to 60 percent reduction in dry weight solids that require dewatering and handling for disposal. An approximate 20 percent makeup volume of commercial ferrifloc is needed when the process is at steady state. A comparison of costs before and after using the iron recovery process shows a 50 percent reduction in annual cost. Approximately one-third of the savings is attributable to recovery of the iron itself. The remaining cost savings is due to the 50 to 60 percent reduction in solids that require dewatering and hauling, and the improved dewaterability of the acidified solids.[145]

Recalcination of Lime Softening Sludge

Lime recovery by recalcination has been used for years.[146] A review of recent literature, however, has failed to find an increase in the use of this sludge management alternative. This situation seems to be due to high energy costs, high initial capital costs, and the presence of impurities in the recovered lime.

Quicklime (CaO) can be produced from lime-softening residues by recalcination following dewatering and drying. Sludge is first gravity-thickened to 18 to 30 percent solids content. It may then be carbonated to redissolve magnesium hydroxide (lowering the magnesium content improves the recalcining process), followed by dewatering to 50 to 65 percent solids. It is then burned at 1800 to 2000 °F. The reaction is:

$$CaCO_3 \rightarrow CaO + CO_2$$

The lime and CO_2 produced can then be reused in treatment. Theoretically, 2 moles of CaO are produced in recalcination but, in practice, only about 20 percent more lime than was initially applied in softening is produced.[147]

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[143] P. E. Pigeon et al., "Recovery and Reuse of Iron Coagulants in Water Treatment," *JAWWA* (October 1979).

[144] D. A. Cornwell et al. (June 1987).

[145] D. A. Cornwell et al. (June 1987).

[146] R. B. Williams and G. L. Culp.

[147] D. A. Cornwell et al. (June 1987).

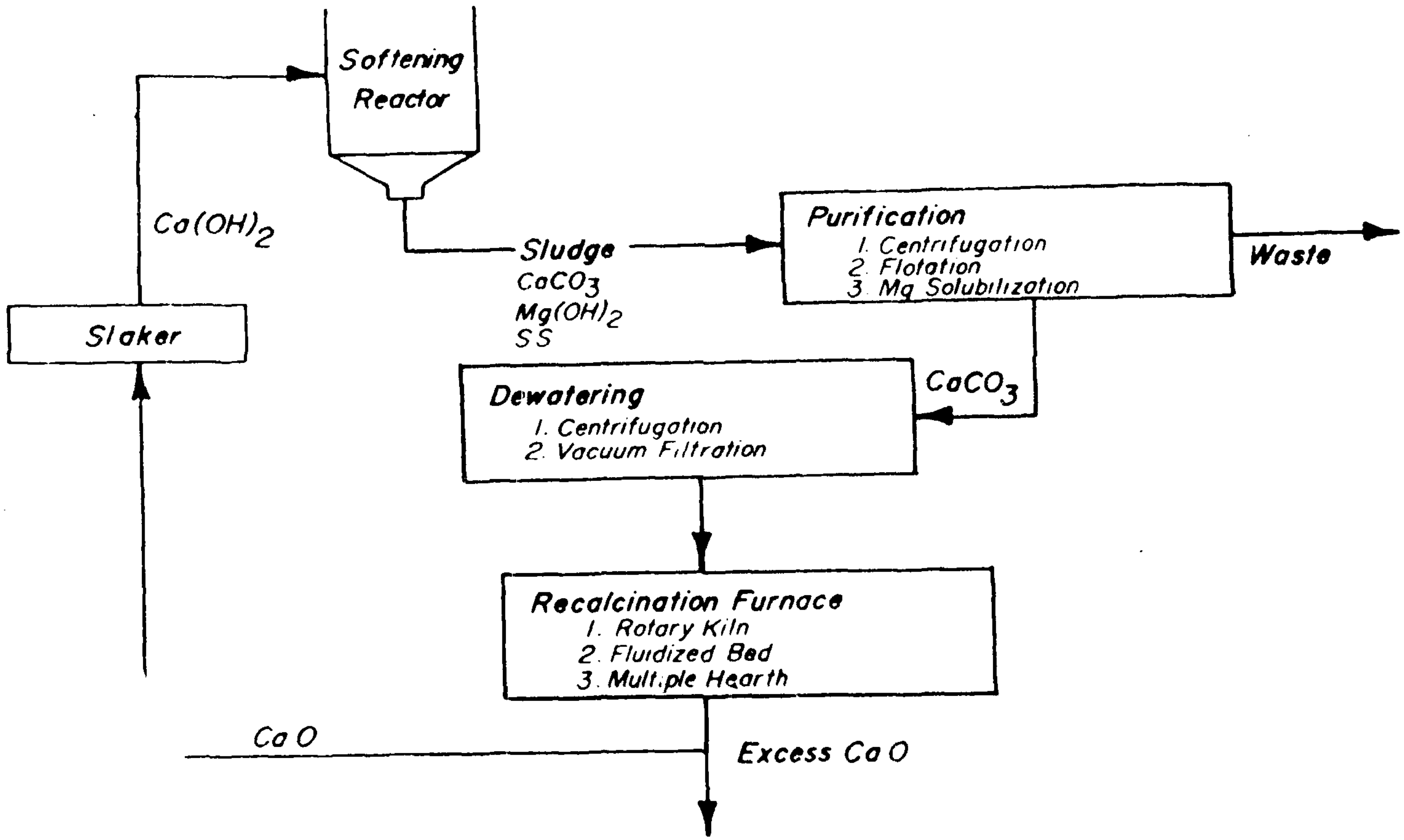

Figure 39. Options for lime recovery. (Source: D. A. Cornwell et al., *Water Treatment Plant Waste Management* [AWWA Research Foundation, June 1987]. Used with permission.)

Various recalcination alternatives have been used as shown in Figure 39. One problem that has inhibited more widespread use of recalcination is that impurities in the sludge either make lime recovery inefficient or the resulting product is not of high quality. Contaminants that are not volatized during calcination will increase with recycle and reuse, causing problems both in the slaking process and in efficient calcination.

The primary impurity affecting calcination in groundwater is magnesium and sometimes silica. Surface waters will also have SS and coagulant hydroxides if these are used in the treatment process.[148] Therefore, as Figure 39 shows, the first step for many plants practicing recalcination is a purification process. The most common method of eliminating impurities from the calcium carbonate sludges is one- or two-stage centrifugation, which uses the specific gravity difference between the calcium carbonate and the impurity to make the separation. Calcium carbonate is heavier than both magnesium hydroxide and silt, and moves to the wall of the centrifuge while the magnesium hydroxide or silt is lost in the centrate. The primary disadvantage of this method is that some calcium carbonate is also lost in the centrate, depending on the amount of impurity present and the required degree of classification. It has been estimated that at least a 91 percent grade of calcium carbonate is needed to be suitable as feed for the recalcination step.[149] If the magnesium content is high, a greater degree of separation is needed and more of the calcium carbonate is lost. In these cases, it may be appropriate to remove the magnesium through selective dissolution by mixing the carbon dioxide from the recalcination stack gases with the sludge.

Available furnace types include the rotary kiln, flash calciner, fluidized-bed calciner, and multiple-hearth calciner. The economics of applying the process primarily depend on the cost of fuel necessary to calcinate the sludge. The fuel consumption is in the range of 8.5 to 12 MBtu/ton of CaO produced. No. 2 fuel oil has a heat value of 141,000 Btu/gal, so that 60 to 90 gal of No. 2 fuel oil are required per ton of CaO produced.[150] High energy use apparently has contributed to the current lack of enthusiasm for the recalcination process; however, calcination of limestone to produce lime used in softening also is energy-intensive.[151]

System Optimization Computer Program for Solid/Liquid Waste Management

Environmental Engineering and Technology, Inc., has developed a computer program compatible with an IBM/PC to allow evaluations of optimal sludge management systems. The program was developed to allow the user to create the sludge treatment and disposal system desired, with the program then showing the anticipated results and cost of implementing such a system. Managers can then use the results to make changes in the system so as to improve cost-effectiveness in subsequent runs. The program is meant to be a tool that allows several combinations to be evaluated quickly, so that the user can determine which areas deserve further attention.

The sludge management program has been combined with a water treatment process program. This process program provides output on sludge and backwash quantities for different plant operating conditions. Therefore, the user can also evaluate the effects of

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[148]D. A. Cornwell et al. (June 1987).
[149]D. A. Cornwell et al. (June 1987).
[150]D. A. Cornwell et al. (June 1987).
[151]R. B. Williams and G. L. Culp.

different coagulants, different lime-softening treatment considerations, and backwashing operations on sludge management decisions.

An example of an input sequence to the sludge management program would be to create the system desired; for example, manual cleaning of basins once per 3 months, a holding basin to equalize flow, a filter press, and landfilling at a site 5 mi away. Output from the program would include sludge characteristics at all stages in the system, the number of units required, chemical demands, and capital and operating costs.[152] The user would then create multiple situations, comparing the end results. The objective is not for the user to design systems, but rather to develop better insights as to which combinations warrant testing or detailed evaluation.

Chapter 5 of the reference Cornwell et al. (June 1987) is the user's manual for this program. It describes the program, limitations and usefulness, and assumptions made in the program's development.

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[152] D. A. Cornwell et al. (June 1987).

6 CONCLUSION

This study has identified options for water treatment plant sludge treatment and disposal at Army installations. The types of waste produced were identified, along with the basic chemical and physical properties. Applicable regulations were reviewed. Treatment methods, disposal options, and their economics were examined.

Many installations will need to consider alternative sludge production/disposal practices due to more stringent regulations that have discouraged direct discharge to surface waters. Because of the variability in raw water quality, treatment methods, and resulting sludge properties, solutions must be developed on a case-by-case basis. Installations can use the information in this report in determining the optimal treatment and disposal methods.

Metric Conversion Factors

1 in.	=	2.54 cm
1 ft	=	0.305 m
1 sq ft	=	0.092 m^2
1 lb	=	0.453 kg
1 ton	=	907.2 kg
1 gal	=	3.785 L
°F	=	(°C x 1.8) + 32

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